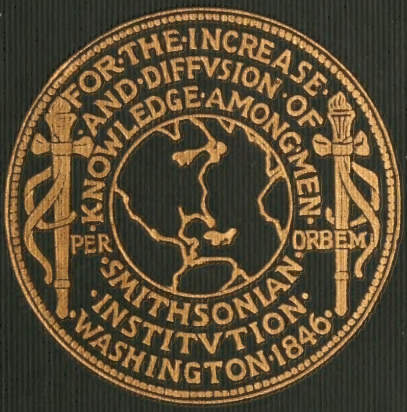

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WASHINGTON·1846·

ANNUAL REPORT OF THE BOARD OF REGENTS OF

THE SMITHSONIAN INSTITUTION

SHOWING THE

OPERATIONS, EXPENDITURES, AND CONDITION OF THE INSTITUTION FOR THE YEAR ENDING JUNE 30

1939



(Publication 3555)

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON: 1940

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - Price $1.50 (cloth cover)

LETTER OF TRANSMITTAL

SMITHSONIAN INSTITUTION,
Washington, December 2, 1939.

To the Congress of the United States:

In accordance with section 5593 of the Revised Statutes of the United States, I have the honor, in behalf of the Board of Regents, to submit to Congress the annual report of the operations, expenditures, and condition of the Smithsonian Institution for the year ended June 30, 1939. I have the honor to be,

Very respectfully, your obedient servant,

C. G. ABBOT, *Secretary.*

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THE SMITHSONIAN INSTITUTION

June 30, 1939

Presiding officer ex officio.—FRANKLIN D. ROOSEVELT, President of the United States.

Chancellor.—CHARLES EVANS HUGHES, Chief Justice of the United States.

Members of the Institution:

FRANKLIN D. ROOSEVELT, President of the United States.
JOHN N. GARNER, Vice President of the United States.
CHARLES EVANS HUGHES, Chief Justice of the United States.
CORDELL HULL, Secretary of State.
HENRY MORGENTHAU, Jr., Secretary of the Treasury.
HENRY HINES WOODRING, Secretary of War.
FRANK MURPHY, Attorney General.
JAMES A. FARLEY, Postmaster General.
CLAUDE A. SWANSON, Secretary of the Navy.
HAROLD L. ICKES, Secretary of the Interior.
HENRY A. WALLACE, Secretary of Agriculture.
HARRY LLOYD HOPKINS, Secretary of Commerce.
FRANCES PERKINS, Secretary of Labor.

Regents of the Institution:

CHARLES EVANS HUGHES, Chief Justice of the United States, Chancellor.
JOHN N. GARNER, Vice President of the United States.
M. M. LOGAN, Member of the Senate.
CHARLES L. MCNARY, Member of the Senate.
ALBEN W. BARKLEY, Member of the Senate.
CHARLES L. GIFFORD, Member of the House of Representatives.
CLARENCE CANNON, Member of the House of Representatives.
WILLIAM P. COLE, Jr., Member of the House of Representatives.
FREDERIC A. DELANO, citizen of Washington, D. C.
JOHN C. MERRIAM, citizen of Washington, D. C.
R. WALTON MOORE, citizen of Virginia.
ROLAND S. MORRIS, citizen of Pennsylvania.
HARVEY N. DAVIS, citizen of New Jersey.
ARTHUR H. COMPTON, citizen of Illinois.

Executive committee.—FREDERIC A. DELANO, JOHN C. MERRIAM, R. WALTON MOORE.

Secretary.—CHARLES G. ABBOT.

Assistant Secretary.—ALEXANDER WETMORE.

Administrative assistant to the Secretary.—HARRY W. DORSEY.

Treasurer.—NICHOLAS W. DORSEY.

Editor.—WEBSTER P. TRUE.

Librarian.—WILLIAM L. CORBIN.

Personnel officer.—HELEN A. OLMSTED.

Property clerk.—JAMES H. HILL.

UNITED STATES NATIONAL MUSEUM

Keeper ex officio.—Charles G. Abbot.
Assistant Secretary (in charge).—Alexander Wetmore.
Associate director.—John E. Graf.

SCIENTIFIC STAFF

Department of Anthropology:

Frank M. Setzler, head curator; W. H. Egberts, chief preparator.

Division of Ethnology: H. W. Krieger, curator; W. W. Hill, assistant curator; Arthur P. Rice, collaborator.

Section of Ceramics: Samuel W. Woodhouse, collaborator.

Division of Archeology: Neil M. Judd, curator; Waldo R. Wedel, assistant curator; R. G. Paine, senior scientific aid; J. Townsend Russell, honorary assistant curator of Old World archeology.

Division of Physical Anthropology: Aleš Hrdlička, curator; Thomas D. Stewart, associate curator.

Collaborators in anthropology: George Grant MacCurdy; D. I. Bushnell, Jr.

Associate in historic archeology: Cyrus Adler.

Department of Biology:

Leonhard Stejneger, head curator; W. L. Brown, chief taxidermist.

Division of Mammals: Gerrit S. Miller, Jr., curator; Remington Kellogg, assistant curator; H. Harold Shamel, senior scientific aid; A. Brazier Howell, collaborator.

Division of Birds: Herbert Friedmann, curator; J. H. Riley, associate curator; Alexander Wetmore, custodian of alcoholic and skeleton collections; Casey A. Wood, collaborator; Arthur C. Bent, collaborator.

Division of Reptiles and Batrachians: Leonhard Stejneger, curator; Doris M. Cochran, assistant curator.

Division of Fishes: Leonard P. Schultz, curator; E. D. Reid, senior scientific aid.

Division of Insects: L. O. Howard, honorary curator; Edward A. Chapin, curator; William Schaus, honorary assistant curator.

Section of Hymenoptera: S. A. Rohwer, custodian; W. M. Mann, assistant custodian; Robert A. Cushman, assistant custodian.

Section of Myriapoda: O. F. Cook, custodian.

Section of Diptera: Charles T. Greene, assistant custodian.

Section of Coleoptera: L. L. Buchanan, specialist for Casey collection.

Section of Lepidoptera: J. T. Barnes, collaborator.

Section of Hemiptera: W. L. McAtee, acting custodian.

Section of Forest Tree Beetles: A. D. Hopkins, custodian.

Division of Marine Invertebrates: Waldo L. Schmitt, curator; C. R. Shoemaker, assistant curator; James O. Maloney, aid; Mrs. Harriet Richardson Searle, collaborator; Max M. Ellis, collaborator; Maynard M. Metcalf, collaborator; J. Percy Moore, collaborator; Joseph A. Cushman, collaborator in Foraminifera; Charles Branch Wilson, collaborator in Copepoda.

Division of Mollusks: Paul Bartsch, curator; Harald A. Rehder, assistant curator; Joseph P. E. Morrison, senior scientific aid.

Section of Helminthological Collections: Benjamin Schwartz, collaborator.

Division of Echinoderms: Austin H. Clark, curator.

DEPARTMENT OF BIOLOGY—Continued.

Division of Plants (National Herbarium): W. R. Maxon, curator; Ellsworth P. Killip, associate curator; Emery C. Leonard, assistant curator; Conrad V. Morton, assistant curator; Egbert H. Walker, aid; John A. Stevenson, custodian of C. G. Lloyd mycological collection.

Section of Grasses: Agnes Chase, custodian.

Section of Cryptogamic Collections: O. F. Cook, assistant curator.

Section of Higher Algae: W. T. Swingle, custodian.

Section of Lower Fungi: D. G. Fairchild, custodian.

Section of Diatoms: Paul S. Conger, custodian.

Associates in Zoology: C. Hart Merriam, Mary J. Rathbun, C. W. Stiles, Theodore S. Palmer, William B. Marshall.

Associate Curator in Zoology: Hugh M. Smith.

Associate in Marine Sediments: T. Wayland Vaughan.

Collaborator in Zoology: Robert Sterling Clark.

Collaborators in Biology: A. K. Fisher, David C. Graham.

DEPARTMENT OF GEOLOGY:

R. S. Bassler, head curator; Jessie G. Beach, aid.

Division of Physical and Chemical Geology (systematic and applied): W. F. Foshag, curator; Edward P. Henderson, assistant curator; Bertel O. Reberholt, senior scientific aid.

Division of Mineralogy and Petrology: W. F. Foshag, curator; Frank L. Hess, custodian of rare metals and rare earths.

Division of Stratigraphic Paleontology: Charles E. Resser, curator; Gustav A. Cooper, assistant curator; Marion F. Willoughby, senior scientific aid; Margaret W. Moodey, aid for Springer collection.

Section of Invertebrate Paleontology: T. W. Stanton, custodian of Mesozoic collection; Paul Bartsch, curator of Cenozoic collection.

Division of Vertebrate Paleontology: Charles W. Gilmore, curator; C. Lewis Gazin, assistant curator; Norman H. Boss, chief preparator.

Associate in Mineralogy: W. T. Schaller.

Associate in Paleontology: E. O. Ulrich.

Associate in Petrology: Whitman Cross.

DEPARTMENT OF ENGINEERING AND INDUSTRIES:

Carl W. Mitman, head curator.

Division of Engineering: Frank A. Taylor, curator.

Section of Transportation and Civil Engineering: Frank A. Taylor, in charge.

Section of Aeronautics: Paul E. Garber, assistant curator.

Section of Mechanical Engineering: Frank A. Taylor, in charge.

Section of Electrical Engineering and Communications: Frank A. Taylor, in charge.

Section of Mining and Metallurgical Engineering: Carl W. Mitman, in charge.

Section of Physical Sciences and Measurement: Frank A. Taylor, in charge.

Section of Tools: Frank A. Taylor, in charge.

Division of Crafts and Industries: Frederick L. Lewton, curator; Elizabeth W. Rosson, senior scientific aid.

Section of Textiles: Frederick L. Lewton, in charge.

Section of Woods and Wood Technology: William N. Watkins, assistant curator.

Section of Chemical Industries: Wallace E. Duncan, assistant curator.

Section of Agricultural Industries: Frederick L. Lewton, in charge.

DEPARTMENT OF ENGINEERING AND INDUSTRIES—Continued.

Division of Medicine and Public Health: Charles Whitebread, associate curator.

Division of Graphic Arts: R. P. Tolman, curator.

Section of Photography: A. J. Olmsted, assistant curator.

DIVISION OF HISTORY: T. T. Belote, curator; Charles Carey, assistant curator; Mrs. C. L. Manning, philatelist.

ADMINISTRATIVE STAFF

Chief of correspondence and documents.—H. S. BRYANT.
Assistant chief of correspondence and documents.—L. E. COMMERFORD.
Superintendent of buildings and labor.—R. H. TREMBLY.
Assistant superintendent of buildings and labor.—CHARLES C. SINCLAIR.
Editor.—PAUL H. OEHSER.
Engineer.—C. R. DENMARK.
Accountant and auditor.—N. W. DORSEY.
Photographer.—A. J. OLMSTED.
Property clerk.—LAWRENCE L. OLIVER.
Assistant librarian.—LEILA F. CLARK.

NATIONAL GALLERY OF ART

Trustees:

THE CHIEF JUSTICE OF THE UNITED STATES.
THE SECRETARY OF STATE.
THE SECRETARY OF THE TREASURY.
THE SECRETARY OF THE SMITHSONIAN INSTITUTION.
DAVID K. E. BRUCE.
DUNCAN PHILLIPS.
DONALD D. SHEPARD.
FERDINAND LAMMOT BELIN.
JOSEPH E. WIDENER.

President.—DAVID K. E. BRUCE.
Vice President.—FERDINAND LAMMOT BELIN.
Secretary and treasurer.—DONALD D. SHEPARD.
Director.—DAVID E. FINLEY.
Administrator.—H. A. MCBRIDE.
Chief Curator.—JOHN WALKER.

NATIONAL COLLECTION OF FINE ARTS

Acting director.—RUEL P. TOLMAN.

FREER GALLERY OF ART

Director.—JOHN ELLERTON LODGE.
Assistant director.—GRACE DUNHAM GUEST.
Associate in archeology.—CARL WHITING BISHOP.
Associate in research.—ARCHIBALD G. WENLEY.
Superintendent.—JOHN BUNDY.

BUREAU OF AMERICAN ETHNOLOGY

Chief.—MATTHEW W. STIRLING.
Senior ethnologists.—H. B. COLLINS, JR., JOHN P. HARRINGTON, JOHN R. SWANTON.

Senior archeologist.—Frank H. H. Roberts, Jr.
Senior anthropologist.—Julian H. Steward.
Associate anthropologist.—W. N. Fenton.
Editor.—Stanley Searles.
Librarian.—Miriam B. Ketchum.
Illustrator.—Edwin G. Cassedy.

INTERNATIONAL EXCHANGES

Secretary (in charge).—Charles G. Abbot.
Chief Clerk.—Coates W. Shoemaker.

NATIONAL ZOOLOGICAL PARK

Director.—William M. Mann.
Assistant director.—Ernest P. Walker.

ASTROPHYSICAL OBSERVATORY

Director.—Charles G. Abbot.
Assistant director.—Loyal B. Aldrich.
Senior astrophysicist.—William H. Hoover.

DIVISION OF RADIATION AND ORGANISMS

Director.—Charles G. Abbot.
Assistant director.—Earl S. Johnston.
Senior physicist.—Edward D. McAlister.
Senior mechanical engineer.—Leland B. Clark.
Associate plant physiologist.—Florence E. Meier.
Junior Biochemist.—Robert L. Weintraub.

REPORT OF THE SECRETARY OF THE SMITHSONIAN INSTITUTION

C. G. ABBOT

FOR THE YEAR ENDED JUNE 30, 1939.

To the Board of Regents of the Smithsonian Institution.

GENTLEMEN: I have the honor to submit herewith my report showing the activities and condition of the Smithsonian Institution and the Government bureaus under its administrative charge during the fiscal year ended June 30, 1939. The first 18 pages contain a summary account of the affairs of the Institution, and appendixes 1 to 11 give more detailed reports of the operations of the National Museum, the National Gallery of Art, the National Collection of Fine Arts, the Freer Gallery of Art, the Bureau of American Ethnology, the International Exchanges, the National Zoological Park, the Astrophysical Observatory, the Division of Radiation and Organisms, the Smithsonian library, and of the publications issued under the direction of the Institution. On page 133 is the financial report of the executive committee of the Board of Regents.

OUTSTANDING EVENTS

Another step toward the realization of the proposed Smithsonian Gallery of Art was taken during the year when the Commission set up by Congress held a competition for a design for the Gallery. The prize-winning design was submitted by Eliel Saarinen, of Birmingham, Mich. The superstructure of the National Gallery of Art, which is now being built on the Mall to house the Mellon art collection and which is a bureau of the Smithsonian Institution, was nearly completed. It is hoped that the art collections may be installed by August 1940. The Institution's latest method of carrying on the diffusion of knowledge—a weekly radio program in cooperation with the United States Office of Education—completed 3 full years on the air in June 1939. It is estimated that some 3,000,000 people hear this educational program each week. A retirement system for employees paid from private Smithsonian funds was approved by the Board of Regents and is to go into effect on July 1, 1939.

The staff of the Astrophysical Observatory completed the enormous task of recomputing the daily solar-constant values from all its observing stations since 1923. It is expected that the final definitive values will be published during the coming year. The Division of Radiation and Organisms celebrated the tenth year of its existence. Many fundamental investigations have been carried out during that time, and in the past year emphasis has been placed on exact studies of phenomena connected with photosynthesis.

M. W. Stirling, Chief of the Bureau of American Ethnology, conducted a very successful archeological expedition to Mexico in cooperation with the National Geographic Society. The most interesting find was a stone monument containing an initial-series date. Dr. Aleš Hrdlička completed the final season's work in his program of anthropological investigations in Alaska begun in 1926. Dr. Waldo L. Schmitt accompanied the Presidential cruise of 1938 to the Galápagos Islands, bringing back very valuable collections in many different fields.

One new member was appointed to the Board of Regents, namely, Representative William P. Cole, Jr., of Maryland, to fill the vacancy created by the resignation from the House of Representatives of Hon. T. Alan Goldsborough.

SUMMARY OF THE YEAR'S ACTIVITIES OF THE BRANCHES OF THE INSTITUTION

National Museum.—The total appropriation actually available during the year was $771,880, which was $3,840 less than the amount available for the previous year. Accessions to the Museum collections, received for the most part as gifts or as the result of Smithsonian expeditions, numbered 368,082 individual specimens. This brings the estimated total number of specimens in the Museum to 16,688,759. Some of the outstanding additions were: In anthropology, a large number of stone implements from Indian sites in Maryland, Virginia, and Alaska, and from Mousterian, Tardenoisian, and Acheulean sites in South Africa, and a set of casts representing the remains of the fossil ape-man of China, *Sinanthropus;* in biology, important marine mammal material representing whales, narwhals, walruses, seals, and porpoises, extensive herpetological collections made in Mexico by Dr. Hobart M. Smith, and 11,000 plant specimens collected in little-known parts of Colombia by E. P. Killip of the Museum staff; in geology, a 153-pound topaz crystal from Brazil, 42 meteorite specimens, 25 of them representing falls new to the Museum, 10,000 Paleozoic fossils from the Ohio and Mississippi Valleys given by John M. Nickles, and numerous fossil vertebrates resulting from

a field expedition to Utah; in engineering and industries, a collection of relics of the aeronautical work of Samuel P. Langley, a former Secretary of the Institution, an original Union aircraft engine of the World War period, and many objects pertaining to transportation, communication, metrology, and other branches of this department; and in history nearly 3,600 objects of historic and antiquarian interest. The usual large number of expeditions were in the field during the year in the interests of anthropology, biology, and geology. These were financed largely by the private funds of the Smithsonian Institution or through the cooperation of other individuals or institutions. Visitors to the Museum buildings totaled 2,233,345 for the year. Fourteen special exhibitions were held under the auspices of various scientific, governmental, and educational agencies. The Museum published an annual report, 4 Bulletins and 1 volume of another, 2 Contributions from the National Herbarium, and 27 Proceedings papers.

National Gallery of Art.—A number of changes in the personnel of the Gallery were made during the year. Paul Mellon, President, resigned in May 1939, and David K. E. Bruce, Vice President, was elected President. The vacancy thus created in the vice presidency was filled by the election of Ferdinand Lammot Belin. Harry A. McBride was appointed Administrator of the Gallery, John Walker was appointed Chief Curator, and Stephen Pichetto was appointed consultant restorer. Joseph E. Widener and Samuel H. Kress were chosen to fill the vacancies created on the Board of Trustees by the resignation of Paul Mellon and the forthcoming expiration on July 1, 1939, of the term of Donald D. Shepard. The outstanding event of the year was the gift to the Gallery by Samuel H. Kress and the Samuel H. Kress Foundation of a collection of Italian paintings and sculpture, stated by experts to be one of the finest private collections of Italian art in the world. The collection was accepted by the Board of Trustees and will be installed in special rooms before the opening of the Gallery. With the Mellon collection and the Kress collection, the Gallery will at once become a center for art study in this country as well as one of the great galleries of the world. Congress appropriated $159,000 for the administrative and operating expenses of the Gallery during the fiscal year beginning July 1, 1939. Temporary offices were established, and a nucleus of the permanent staff was assembled for actual appointment on July 1, 1939. The superstructure of the Gallery building was practically completed at the close of the year, and it is hoped that by August 1, 1940, construction will be far enough advanced so that the art collection may be installed. Over $5,000,000 had been actually expended for con-

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struction by the close of the year; the total cost, it is estimated, will be more than $15,000,000.

National Collection of Fine Arts.—The exhibition gallery of the National Collection was closed during the last 4 months of the year for renovation. Weak plaster was replaced, the woodwork painted, and the walls covered with rubber-backed monk's cloth. The eighteenth annual meeting of the Smithsonian Art Commission was held on December 6, 1938, and four art works submitted during the year were accepted for the National Collection. Two miniatures were acquired through the Catherine Walden Myer fund. Six special exhibitions were held as follows: The Eberstadt collection of 260 naval historical prints; architectural exhibition of photographs of representative buildings of the post-war period; 200 prints by graphic artists, Federal Art Project, Works Progress Administration; 76 water-color paintings of the flora of the Isthmus of Panama by Marie Louise Evans; 173 water-color sketches of wild flowers of various national parks by Mary Vaux Walcott; 56 oil paintings, 38 drawings, 4 water colors, and 3 pastels by Joel J. Levitt.

Freer Gallery of Art.—Additions to the collections included Chinese bronze, jade, and paintings; an Arabic manuscript; and East Indian painting. Curatorial work was devoted to the study of these new acquisitions and to other Chinese, Japanese, Arabic, Persian, East Indian, and Armenian manuscripts or art objects either already in the collection or submitted for purchase. In addition, information on 1,386 similar objects and 586 photographs of objects was furnished to the owners, who wished to know their identity, provenance, quality, date, meaning of inscriptions, etc. Changes in exhibition involved a total of 71 objects. The total number of visitors for the year was 102,936. An illustrated lecture on "Essentials in Chinese Painting" was given by Dr. Osvald Sirén, Curator of Oriental Arts, National Museum, Stockholm, on March 15, 1939. Eighteen groups were given instruction in the various rooms, and six groups were given docent service in the exhibition galleries.

Bureau of American Ethnology.—Mr. Stirling, Chief of the Bureau, directed an archeological expedition to southern Veracruz, Mexico, in cooperation with the National Geographic Society, which financed the expedition. Nine major stone monuments were excavated, and a large collection of ceramics and figurines was obtained. The most interesting discovery was a stone monument inscribed with an initial-series date. Dr. Swanton continued his field and office work connected with his study of De Soto's route, and completed his report as chairman of the United States De Soto Expedition Commission. The 400-page report was published in May 1939 as a House document. Dr. Harrington continued his

study of the northern provenience of the Navaho Indians, and in May 1939 he went to California to check with native informants certain recently discovered documents relating to the Sacramento Valley Indians. Dr. Roberts continued his investigations of Folsom man at the Lindenmeier site in northern Colorado, bringing to light more material evidence of this early American culture. Dr. Steward continued his archeological and ethnological reconnaissance in western South America, in preparation for the editing of the proposed Handbook of South American Indians, and completed preparations for the actual beginning of this project. Mr. Collins, newly appointed ethnologist in the Bureau by transfer from the National Museum, worked over the large collection of prehistoric Eskimo artifacts, several thousand in number, which he excavated on a previous expedition to Cape Prince of Wales and other points in the vicinity of Bering Strait. Dr. Fenton, appointed to the staff of the Bureau in February 1939, wrote up the results of his previous investigations among the Iroquois. Miss Densmore, a collaborator of the Bureau, submitted two manuscripts entitled "Choctaw War and Dance Songs" and "Choctaw and Seminole Songs." Mr. Carter, another collaborator, worked with the ethnographic and Indian sign-language material contained in the manuscripts of the late Maj. Gen. Hugh L. Scott. The Bureau published its annual report and six bulletins.

International Exchanges.—The International Exchange Service under the Smithsonian Institution acts as the official agency of the United States for the interchange with other countries of governmental and scientific documents. The number of packages of such material passing through the Exchange Service during the year was 714,877, and the weight of these packages was 719,694 pounds. Shipments to Spain were still suspended at the close of the year, but efforts were being made through diplomatic channels to resume exchange relations. There are now being sent through the Exchange Service to foreign countries 61 full sets of United States official documents and 47 partial sets. One hundred and three copies of the Congressional Record and the Federal Register are now sent to foreign depositories. A very appreciative letter was received from Dr. T. L. Yuan, officially connected with the Library Association of China, thanking the Exchange Service for its part in assembling and forwarding a total of more than 36,000 packages of publications presented by individuals and establishments throughout this country.

National Zoological Park.—Extensive improvements to the grounds, including large grading projects, building of a stone feed house, constructing buffalo paddocks, laying of new concrete walks,

repairing of roads, and other similar work, were completed during the year through W. P. A. assistance. The Public Works Administration allotted $90,000 for a much-needed restaurant building. The Director made a trip to the Argentine, bringing back 70 crates of live animals numbering 316 individuals of 58 different species. Visitors for the year totaled 2,201,080, including 37,220 students from 699 different schools in 22 States and the District of Columbia. As usual, many specimens were received as gifts, among the most interesting of which were 10 Louisiana herons and 11 snowy egrets from A. E. McIlhenny, Avery Island, La., and a fine collection of Central American reptiles from Costello Craig, Washington, D. C. Forty-eight mammals were born and 15 birds were hatched in the Zoo during the year. The total number of animals in the collection at the close of the year was 2,450. The Zoo now has four excellent exhibition buildings, but there remain three that are old and unsatisfactory, namely, those housing lions, monkeys, and antelopes. The greatest need of the Zoo is the replacement of these three buildings with modern structures.

Astrophysical Observatory.—The recomputation of all solar-constant values since 1923 was practically completed, the only remaining work being the final corrections and general discussion, which are expected to be concluded by October 1939. The entire revision will then be published. The Director spent considerable time in preparing a reply to criticisms of the solar-constant work published by Dr. M. M. Paranjpe in the Quarterly Journal of the Royal Meteorological Society. Observations of the solar constant were begun at the new station on Burro Mountain, near Tyrone, N. Mex. Exceptional snowfall occurred there during the winter, but it is expected that other years will be very favorable for observations. Solar-constant observing has been continued at the other two stations at Table Mountain, Calif., and Montezuma, Chile, on every favorable day. W. H. Hoover set up apparatus in the 100-inch telescope building on Mount Wilson for measuring the distribution of energy in the spectra of the brighter stars and observed with considerable success on August 31 and September 21, 1938. As a result, it is believed that with certain improvements in the apparatus it will be possible to obtain continuous, automatically recorded stellar spectrum energy curves, probably at least 10 centimeters high at maximum, for the brightest stars when the 200-inch telescope becomes available.

Division of Radiation and Organisms.—The year 1939 marked the tenth anniversary of the establishment of the Division. During that period notable progress has been made both in developing physical equipment and in building up a permanent scientific staff. Numerous fundamental investigations have been carried out, with the result that

members of the staff are frequently consulted on research problems in the field of radiation as related to living organisms. During the year the attention of the staff was concentrated on photosynthesis, factors influencing plant growth, and the stimulative action of ultraviolet radiation. Experimental evidence was obtained which indicates the formation during photosynthesis of a material which combines with or absorbs carbon dioxide. This compound, or "intermediate," appears to be chlorophyllous in nature. Apparatus and method were developed for the determination of small amounts of chlorophyll, the sensitivity with a 5-centimeter absorption cell being $\frac{1}{10000}$ milligram of chlorophyll. Further progress was made in the investigation of suitable artificial illumination for the growth of plants under controlled conditions. Studies were continued on the relation of light to internode development. The effect of radiation on the growth of excised roots and leaves was investigated. Continuation of the studies on the stimulative action of ultraviolet light showed that sublethal exposure of the green alga *Stichococcus bacillaris* to certain short wave lengths of the ultraviolet caused increased cell multiplication. This stimulative action is not transitory but has persisted in the cultures over a period of 2 years. Three papers by members of the staff on these researches were published, and others were in press at the close of the year.

THE ESTABLISHMENT

The Smithsonian Institution was created by act of Congress in 1846, according to the terms of the will of James Smithson, of England, who in 1826 bequeathed his property to the United States of America "to found at Washington, under the name of the Smithsonian Institution, an establishment for the increase and diffusion of knowledge among men." In receiving the property and accepting the trust, Congress determined that the Federal Government was without authority to administer the trust directly, and, therefore, constituted an "establishment" whose statutory members are "the President, the Vice President, the Chief Justice, and the heads of the executive departments."

THE BOARD OF REGENTS

The only change in the Board of Regents during the year was the appointment by the Speaker of the House of Representatives, on April 12, 1939, of Representative William P. Cole, Jr., of Maryland, to fill the unexpired term of Representative T. Allan Goldsborough, who resigned from the House of Representatives.

The roll of Regents at the close of the year was as follows: Charles Evans Hughes, Chief Justice of the United States, Chancellor; John

N. Garner, Vice President of the United States; members from the Senate—M. M. Logan, Charles L. McNary, Alben W. Barkley; members from the House of Representatives—Charles L. Gifford, Clarence Cannon, William P. Cole, Jr.; citizen members—Frederic A. Delano, Washington, D. C.; John C. Merriam, Washington, D. C.; R. Walton Moore, Virginia; Roland S. Morris, Pennsylvania; Harvey N. Davis, New Jersey; and Arthur H. Compton, Illinois.

Proceedings.—The annual meeting of the Board of Regents was held on January 12, 1939. The Regents present were Chief Justice Charles Evans Hughes, Chancellor; John N. Garner, Vice President of the United States; Senator M. M. Logan; Representatives T. Alan Goldsborough and Charles L. Gifford: Citizen Regents Frederic A. Delano, John C. Merriam, R. Walton Moore, Harvey N. Davis and Arthur H. Compton; and the Secretary, Dr. Charles G. Abbot.

The Secretary presented his annual report, covering activities during the year of the parent institution and of the several Government branches, and Mr. Delano presented the report of the executive committee, covering financial statistics of the Institution. The Board accepted these reports.

The Secretary also presented the annual report of the Smithsonian Art Commission, the membership of which is as follows: Charles L. Borie, Jr., Chairman; Frank Jewett Mather, Jr., Vice Chairman; Charles G. Abbot (ex officio), Secretary; and Herbert Adams, Louis Ayres, Gifford Beal, Gilmore D. Clarke, George H. Edgell, David E. Finley, James E. Fraser, Frederick P. Keppel, John E. Lodge, Paul Manship, George B. McClellan, Edward W. Redfield, Mahonri M. Young.

In his usual special report the Secretary mentioned briefly the more important activities carried on by the Institution and its bureaus during the year.

FINANCES

A statement will be found in the report of the executive committee, page 133.

MATTERS OF GENERAL INTEREST

THE SMITHSONIAN GALLERY OF ART

On May 17, 1938, the President approved a congressional resolution which authorized him to set aside ground on the Mall for a Smithsonian Gallery of Art. The resolution also created the Smithsonian Gallery of Art Commission, which was authorized to obtain a design for a "suitable building for properly housing and displaying the national collections of fine arts and * * * to exhibit the works of artists worthy of recognition." An appropriation of $40,000

was authorized for this purpose, and that amount was provided in the Second Deficiency Act approved June 25, 1938. The members of the Commission are:

C. G. Abbot, Secretary of the Smithsonian Institution;
Edward Bruce, Chief of the Section of Fine Arts in the Treasury Department;
Frederic A. Delano, Chairman of the National Capital Park and Planning Commission;
Gilmore D. Clarke, Chairman of the Commission of Fine Arts;
Hon. Alben W. Barkley, chairman of the Joint Committee on the Library, United States Senate;
Hon. Kent E. Keller, chairman of the Committee on the Library, House of Representatives;
Charles L. Borie, Jr., Chairman of the Smithsonian Art Commission.

The Commission appointed as its professional adviser, Joseph Hudnut, professor of architecture in Harvard University, and as its technical adviser, Thomas Mabry, executive director of the Museum of Modern Art in New York City. The duty of these two men was to prepare a program of the proposed competition to select an architect for the Smithsonian Gallery of Art and to conduct the competition itself.

A jury of award was set up by the Commission, consisting of Frederic A. Delano, Chairman, and four prominent architects—John A. Holabird, of Chicago; Walter Gropius, of Cambridge; George Howe, of Philadelphia; and Henry R. Shepley, of Boston. The program of competition was issued January 21, 1939, all drawings for the preliminary competition to be submitted by April 29. On May 13 the Commission met at the Smithsonian Institution to receive notice of the awards in the preliminary competition. The 10 best designs, making those submitting them eligible for the final competition, were those of the following:

Paul P. Cret, Philadelphia;
Percival Goodman, New York City;
Phillip L. Goodwin, New York City;
Harry F. Manning, Chicago;
James A. Mitchell, Pittsburgh;
Eliot F. Noyes, Cambridge;
G. Holmes Perkins, Cambridge;
Peter and Stubbins, Boston;
Eliel and Eero Saarinen, Birmingham, Mich.;
Edward D. Stone, New York City.

Honorable mention was awarded to 16 other competitors.

The 10 prize winners entered the final competition, and on June 29, 1939, the Commission met again at the offices of Mr. Bruce in the Procurement Division of the Treasury Department to receive the final report of the jury of award. The first prize of $7,500 was

awarded to Eliel Saarinen, the second prize of $3,500 to Percival Goodman, and each of the eight remaining competitors received the third prize of $1,000.

The Commission then requested the Procurement Division of the Treasury to submit a proposal for the construction of a model of the Saarinen design on a scale of ⅛-inch=1 foot and appropriated $1,500 for this purpose. As the resolution creating the Commission required the approval of the successful design by the Board of Regents of the Smithsonian Institution, the Commission submitted a report of their action to that Board.

It was contemplated in the congressional resolution that the building for the Smithsonian Gallery of Art would be constructed with private funds, and the Regents of the Institution were authorized to solicit and receive subscriptions of funds for that purpose. At the close of the year no funds had been raised.

SMITHSONIAN RADIO PROGRAM

"The World is Yours," the Smithsonian radio program put on the air in cooperation with the United States Office of Education, the National Broadcasting Co., and the Works Progress Administration, completed its third year of consecutive weekly half-hour programs in June 1939. The Institution selects the subjects of the broadcasts, furnishes the necessary information to the script writer, and corrects the scripts and supplementary articles. The Office of Education is responsible for the writing of the scripts and supplementary articles and, with the National Broadcasting Co., for the production of the broadcasts. Time on the air is given by the National Broadcasting Co., and financial support by the Works Progress Administration.

The series has continued to increase in popularity, as indicated by the larger number of letters received in the last 6 months of the year. At the close of the year more than 350,000 letters had been received as a result of the broadcasts, but for the last 6-month period the number was 106,000, a decided increase over any previous similar period. Several marks of recognition came to the program during the year: It was named by the National Women's Radio Committee as the most popular of all adult education programs; in a poll of 750,000 votes taken by the magazine Radio Guide, "The World is Yours" stood fourth among the 12 leading educational programs, the only three ahead of it being "American School of the Air," "Great Plays," and "Music Appreciation Hour"; and one of the scripts received honorable mention at the annual meeting of the Institute for Education by Radio held at Columbus, Ohio, in May 1939. A num-

ber of published articles by radio education experts have praised the program; for example, an authority of the Ohio State University writes:

> "The World is Yours" * * * has demonstrated beyond question that interest in the arts and sciences can be increased on a nationwide scale by means of radio. "The World is Yours" is probably the finest example that American radio has to offer of the use of ingenious techniques, sound effects, and musical background to produce a deep and lasting educational effect on the listener.

The number of stations carrying the program every Sunday has steadily increased, until at the close of the year the number stood at 78, almost the maximum possible on the N. B. C. red network. It is also carried on a short-wave station at Schenectady for foreign listeners, and is rebroadcast at a different hour by at least one independent station. The scripts are available to schools, clubs, and others interested through the Office of Education script exchange.

The subjects of the broadcasts, selected by the Institution, are widely diversified, as will be seen by examining the list given below, but they are also carefully arranged—though this may not be so apparent on a casual inspection of the list—so that the broad subjects covered by Smithsonian activities come around in fairly regular rotation. These broad classifications include physical science, astronomy, biology, geology, anthropology, engineering and industries, history, art, and exploration. The subjects covered during the past year were as follows:

	1938
Independence Hall	July 3
History of the Earth	July 10
Invention of the Steamboat	July 17
Great Astronomers	July 24
The Potter's Art	July 31
Inland Waterways	Aug. 7
Crustaceans	Aug. 14
Communications	Aug. 21
Seven Ages of Geology	Aug. 28
Battle against Disease	Sept. 4
Lead	Sept. 11
Army and Navy Uniforms	Sept. 18
Balboa and the Discovery of the Pacific	Sept. 25
Fur-bearing Animals	Oct. 2
Eskimo	Oct. 9
Insects vs. Forests	Oct. 16
Heros and Heroines	Oct. 23
Great Engineering Feats	Oct. 30
LaSalle on the Mississippi	Nov. 6
Progress in Science	Nov. 13
Aircraft in the World War	Nov. 20
Romance of Rivers	Nov. 27
Microscopic Animals	Dec. 4

	1938
Arctic Explorers	Dec. 11
Petroleum	Dec. 18
History of Dolls and Toys	Dec. 25
	1939
Early Wings for Commerce	Jan. 1
Modern Wings for Commerce	Jan. 8
Pushing Back History	Jan. 15
The Geologist Detective	Jan. 22
Our Island Universe	Jan. 29
Pearls and Oysters	Feb. 5
Great American Biologists	Feb. 12
Story of Aluminum	Feb. 19
Cave and Cliff Dwellers	Feb. 26
Modern Medicine	Mar. 5
Animals of Fable	Mar. 12
The Air above Us	Mar. 19
Eli Whitney—Cotton's Man of Destiny	Mar. 26
Gems and Gem Lore	Apr. 2
First Ladies' Fashions	Apr. 9
Trail Blazing with Science	Apr. 16
Head Hunters	Apr. 23
New Frontiers of Physics	Apr. 30
From New York to Washington by Coach in 1800	May 7
The Lewis and Clark Expedition	May 14
Model Airplanes	May 21
Salt from the Earth	May 28
Old-Fashioned Gardens	June 4
Growth of the American Flag	June 11
Fishing around the World	June 18
The Miracle of Paper	June 25

Supplementary articles on each subject, known as listener-aids, were sent after each broadcast to those requesting them. In this way the educational value of the programs is extended and put on a more lasting basis, as the listener-aids can be preserved for reference use.

The continuation of "The World is Yours" is assured for the coming year. The Institution has been grateful to the Office of Education, the National Broadcasting Co., and the W. P. A. for making available this new means of diffusing knowledge. In point of numbers reached, in interest aroused, and in lasting educational value, this series of broadcasts has perhaps been the most effective method the Institution has ever used for the "diffusion of knowledge among men."

WALTER RATHBONE BACON TRAVELING SCHOLARSHIP

The Walter Rathbone Bacon traveling scholarship of the Smithsonian Institution was awarded at the beginning of the year to Dr. Hobart M. Smith for a period of 2 years. The purpose of Dr.

Smith's investigation is the accumulation of specimens of reptiles and amphibians from Mexico, on the basis of which, combined with material already available from Mexico, a herpetology of Mexico may be compiled and the biotic provinces of the country more accurately defined.

Reports received from Dr. Smith in the field state that collecting began on October 5. Up to the close of the year he had worked in Chihuahua, Coahuila, Tamaulipas, central Veracruz, Morelos and Guerrero, as well as in the lakes of the valleys of Mexico and Toluca, on the southern edge of the plateau in Michoacán, and in the vicinity of Piedras Negras, Guatemala. Approximately 8,100 specimens had been taken, representing 360 species, of which at least 10 were new.

SMITHSONIAN INSTITUTION EMPLOYEES RETIREMENT SYSTEM

The important matter of a retirement system for employees who receive all or a portion of their salaries from the private funds of the Institution was taken up during the year. Many of the Institution's employees and all those of the Government bureaus under its administration receive their compensation from the Federal Government, placing them automatically under the Government retirement system. But for the remaining employees, who receive all their compensation from private Smithsonian funds, there has been no definite plan to cover retirement or disability. Nor has there been any arrangement for supplementary benefits for those who receive a part of their compensation from the Government and a part from the Smithsonian. To remedy these conditions I asked a committee of three employees to study the matter and draw up a plan for a retirement system to cover such employees.

In November 1938 such a plan was completed and submitted to an actuary for expert opinion. With certain suggested modifications, the plan was pronounced to be sound. It was then presented to the Permanent Committee of the Board of Regents, who recommended to the Board that it be put into operation. The Board so voted, and the retirement system therefore goes into effect on July 1, 1939.

The Smithsonian retirement system is in its general plan modeled on the Government system for Federal employees, but is modified to meet the special conditions of a private foundation such as the Smithsonian Institution. A retirement board is provided for, to be appointed by the Secretary, which, with his approval, shall decide questions arising under the operation of the retirement system.

With the adoption of this system, the retirement for age or disability of every employee of the Institution and its branches is definitely provided for.

NEW EXHIBITS IN THE SMITHSONIAN MAIN HALL

For many years past the only public exhibits in the Smithsonian building have been those of the division of graphic arts. They were exhibited there only because of the crowded condition of the National Museum buildings, and the arrangement was intended to be only temporary. Having realized for some time that it would be desirable to set up in the Smithsonian main hall a comprehensive exhibit that would tell visitors the story of all Smithsonian activities, I took steps during the year toward the accomplishment of this aim.

As the Smithsonian Institution has grown and expanded its field of activity during the years, more bureaus have been placed under its administration, more buildings have been added to the Smithsonian group, and many new types of investigation have been undertaken. With the growing complexity of the organization, it has become very difficult for visitors to the several buildings to form a picture of the Institution as a whole or to get any definite conception of its functions and purposes.

To remedy this situation I appointed a committee to recommend plans for a series of exhibits in the Smithsonian main hall that would portray in popular form the work of the Institution in many branches of science, as well as the relationship between the parent Institution and the National Museum, National Gallery of Art, and all its other branches. It was emphasized that the exhibits should be of such a nature that they could be changed readily to keep them up to date.

It was planned also that as these exhibits developed, they would form an important part of the proposed centennial celebration of the Institution in 1946.

Carl W. Mitman, Head Curator of Engineering and Industries, was placed in charge of the exhibit project, and he selected to work with him as a committee, Messrs. Foshag, Friedmann, Setzler, and True of the Institution's staff. One meeting of the committee was held during the year to discuss preliminary plans, and it was expected to begin the preparation of the hall and the installation of the new exhibits during the coming fall and winter.

EIGHTH ARTHUR LECTURE

The Arthur lecture, under the auspices of the Institution, was provided for in the will of the late James Arthur, of New York, who in 1931 left to the Smithsonian Institution a sum of money, a part of the income from which should be used for an annual lecture on some aspect of the study of the sun.

The eighth Arthur lecture was given on February 21, 1939, by Dr. Herbert J. Spinden, curator of American Indian art and primitive cultures of the Brooklyn Museum, his subject being "Sun Worship."

The lecture, held in the auditorium of the National Museum, constituted also the six hundred and eighty-fourth meeting of the Anthropological Society of Washington. The paper will be published in the General Appendix to the Smithsonian Report for 1939.

EXPLORATIONS AND FIELD WORK

A number of States in the United States and many foreign countries were visited by Smithsonian representatives during the calendar year 1938, resulting in the acquisition of many specimens for the Institution's study series and in the collection of valuable scientific data for "the increase of knowledge."

On the invitation of the President, Dr. Waldo L. Schmitt participated in the cruise to the Galápagos Islands. In addition to a host of other scientific material—geological, botanical, and zoological—250 individual fish, representing about 60 different species, were brought back to the Museum for study and permanent preservation.

A. F. Moore, under my direction, established a new solar observatory on Burro Mountain, near Tyrone, N. Mex., where he hopes to obtain good observations. The new station will be particularly useful from December through February, when the other two stations lose many days. W. H. Hoover spent 5 months on Mount Wilson, Calif., experimenting with the growth of plants in nearly monochromatic rays selected from the solar spectrum, and measuring the distribution of radiation in the spectra of the brighter stars, using the 100-inch telescope.

Dr. R. S. Bassler studied some well-known fossil areas in southern England and obtained, in addition to specimens needed to fill certain gaps in the Museum's study series, information for more accurate labeling of invertebrate fossil material already in the collections. Dr. C. Lewis Gazin continued his investigation of occurrences of the earliest mammals and lizards in Utah and brought back a quantity of material representative of Paleocene and Cretaceous fauna, including one lizard specimen so nearly complete as to be worthy of permanent exhibition in the Museum. Dr. G. Arthur Cooper made a study of Middle Devonian strata in the Catskills of New York, and collected paleontological specimens from that region.

Dr. William M. Mann visited zoos in 15 European cities, where great progress has been made in the exhibiting of animals and where some interesting breeding experiments are being made. Dr. Remington Kellogg, on a visit to Norway, Sweden, England, and Scotland, examined and studied cetacean skeletal material in a number of the museums of those countries. W. M. Perrygo undertook a survey of a large part of Kentucky to collect bird and mammal specimens to add to the Museum's very meager representation from that State. C. R. Aschemeier obtained 28 turtles and 1,862 fish from

Florida waters; and Dr. Leonard P. Schultz collected a variety of fishes from the rivers and streams of Virginia. Capt. Robert Bartlett again conducted a cruise to northwest Greenland, and brought back specimens of marine life from the sea floor, as well as narwhals, walrus pups, and birds. Austin H. Clark continued his exhaustive study of the butterflies of Virginia.

Dr. Erzsébet Kol, of Szegēd, Hungary, reported the results of her study of the algae on the snowfields and glaciers of Alaska in 1936, which was made under a grant from the Smithsonian Institution.

Frank M. Setzler explored a cave in Richland Canyon near the Pecos River in southwestern Texas and unearthed many artifacts of the prehistoric cave dwellers of that region. Dr. Aleš Hrdlička, in his tenth season of work in the Far Northwest, directed an expedition to the Aleutian and the Commander Islands to obtain further light on the existence and extension in the Aleutian Islands of the pre-Aleut stock, to determine definitely whether or not the Commander Islands served as a part of the bridge for the coming of man from Asia, and to reexamine burial caves discovered in 1936–37. Dr. T. D. Stewart carried on excavations on the shore of the Potomac in Virginia, where he uncovered the main part of the ancient Indian village of Patawomeke. Dr. Waldo R. Wedel excavated a group of small mounds in Platte County, Mo., and investigated caves, reported to have disclosed traces of Indian occupancy, in southeastern Colorado. Dr. John R. Swanton continued his reconnaissance of the territory through which De Soto passed on his journey to the Mississippi. Dr. Frank H. H. Roberts, Jr., sought further information on Folsom man at the Lindenmeier site in Colorado, and at sites in Nebraska, Wyoming, and Saskatchewan, Canada, and obtained valuable data on this and associated cultures. Dr. Julian H. Steward spent several months in anthropological reconnaissance in Panama, Ecuador, and Peru, and visited many sites of archeological importance and historical appeal.

PUBLICATIONS

The Institution's publications constitute its primary means of diffusing knowledge. Its other methods comprise museum and art gallery exhibits, radio broadcasts, popular science news releases, and correspondence, but for world-wide dissemination of the results of its scientific researches it depends on its several series of publications. There are at present 13 different series, as follows:

Smithsonian Institution:

- Annual Report (with general appendix reviewing progress in science).
- Miscellaneous Collections.
- Contributions to Knowledge (suspended).
- Special Publications.

National Museum:
Annual Report.
Bulletin.
Proceedings.
Contributions from the National Herbarium.
Bureau of American Ethnology:
Annual Report.
Bulletin.
Astrophysical Observatory:
Annals.
National Collection of Fine Arts:
Catalog.
Freer Gallery of Art:
Oriental Studies.

The total number of publications issued by the Institution and its branches during the year was 99, of which 58 were issued by the Institution proper, 35 by the National Museum, and 6 by the Bureau of American Ethnology. Detailed information regarding these publications will be found in the report of the editor, appendix 11. The number of publications distributed was 162,030.

The printing and binding appropriation for the year covered by this report was increased slightly over that for the preceding year, and a further increase has been granted for the coming year, making the 1940 appropriation $73,000. Although these small increases are of material assistance in catching up arrears of printing and binding, nevertheless the appropriations are still far short of the normal requirements. To keep pace with the manuscript output of the staff and with the binding requirements of the Smithsonian library, $100,000 a year is needed. Anything short of this amount necessitates the holding over of many manuscripts each year, with consequent delay in the publication of the results of original scientific research. This delay—running sometimes to several years for the larger manuscripts—is detrimental to the morale of the scientific staff.

LIBRARY

A total of 11,913 volumes and pamphlets were added to the Smithsonian library during the year. These were received mainly through gift and exchange. The total holdings of the library now stand at 899,327, exclusive of thousands of unbound or incomplete publications. Outstanding among the many gifts was that of 1,636 publications on the history, art, science, and literature of China, from Mrs. Eugene Meyer. Other important gifts were 1,294 scientific journals from Dr. J. R. Swanton, and 879 from Henry Otten. The exchange work of the library involved the receipt of 24,600 packages of publications. In addition to handling this material, the staff made 25,176 periodical

entries, cataloged 7,298 publications, prepared and filed 41,676 catalog and shelf list cards, borrowed 2,516 publications and loaned 11,559, and substantially advanced the union catalog, in addition to many special activities. Volumes bound totaled 546, which was only a fraction of the number waiting to be bound. The chief need of the library, therefore, is increased allotments for binding.

Respectfully submitted.

C. G. Abbot, *Secretary.*

APPENDIX 1

REPORT ON THE UNITED STATES NATIONAL MUSEUM

SIR: I have the honor to submit the following report on the condition and operation of the United States National Museum for the fiscal year ended June 30, 1939:

Funds provided for the maintenance and operation of the National Museum for the year totaled $778,380. A compulsory administrative reserve of $6,500 reduced this to $771,880 actually available for the year, which was $3,840 less than the amount available in 1938.

COLLECTIONS

New material added to the Museum collections was received in 1,766 separate accessions, totaling 368,082 individual specimens. For the most part these additions were gifts from individuals or represented expeditions sponsored by the Smithsonian Institution. They were distributed among the five departments as follows: Anthropology, 13,076; biology, 318,233; geology, 31,689; engineering and industries, 1,493; and history, 3,591. All the accessions are listed in detail in the full report on the Museum, printed as a separate document, but the more important are summarized below. The total number of catalog entries in all departments is now estimated to be 16,688,759.

Anthropology.—In archeology, a large number of stone implements were received, representing Indian sites in Maryland, Virginia, and Alaska; others, of Mousterian, Tardenoisian, and Acheulean age, came from South Africa. Over 9,000 stone, bone, and shell artifacts and ornaments, previously accessioned but not until now cataloged, resulted from the 1933–34 Smithsonian-C. W. A. investigations at the old Yokuts village site near Taft, Calif. Ethnological specimens of interest include a collection of Menominee birch-bark baskets and trays embroidered with porcupine quills, Aleut hunting paraphernalia, a large number of weapons of wild Philippine tribes, Persian and Moorish filigree and cutwork brasses, Chinese jewelry, and Eskimo artwork wrought in mammal and bird skins. About 550 ceramic specimens were received, including a collection of American art pottery (1850–1920) made by the late Dr. Marcus Benjamin, former editor of the National Museum. The famous "gold piano," a Steinway concert grand No. 100000, which was used for 35 years

at the White House, was received by transfer. The division of physical anthropology received important material from sites in the Potomac River Valley, Alaska, and Georgia. An outstanding gift was received from the National Geological Survey of China—a set of casts representing the remains of the fossil ape man *Sinanthropus*.

Biology.—More than 318,000 biological specimens were accessioned during the year. Important marine-mammal material received, which was obtained through the cooperation of the United States Coast Guard, included two complete sets each of whalebone from the Australian and the Alaskan humpback whales; seven fetal skulls of blue whales and finbacks; a pair of lower jaws measuring 24 feet long and weighing a ton each, from a 92-foot Antarctic blue whale; and 13 skulls and skeletons of narwhals, walruses, seals, and porpoises from the 1938 Bartlett Greenland expedition. Many representative series of land mammals were also added, mostly from Africa, India, British Columbia, and the Southeastern United States.

Important avian accessions included birds collected in Veracruz by Dr. Alexander Wetmore, a collection of over 3,000 skins made by the late Dr. Stuart T. Danforth, about 1,050 birds from Kentucky collected for the Museum by W. M. Perrygo and associates, and 35 birds from Clipperton Island taken during the Presidential cruise of 1938.

Large increase in the Museum's herpetological series resulted from extensive collections made in Mexico by Dr. Hobart M. Smith, present incumbent under the Walter Rathbone Bacon traveling scholarship of the Smithsonian Institution. Another valuable collection of reptiles and amphibians received was made by Dr. W. Gardner Lynn in Jamaica. More than 3,200 fishes, mostly from Panama and Nicaragua, and including many holotypes and paratypes, were transferred from the United States Bureau of Fisheries, and 4,600 from the Tennessee Valley Authority. The Presidential cruise yielded 242 fishes from the Galápagos region. In addition, Dr. L. P. Schultz and E. D. Reid collected nearly 6,500 fishes in Virginia for the Museum. Other valuable ichthyological specimens came from the International Fisheries Commission, the Bass Biological Laboratory, the British Museum, and the Academy of Natural Sciences of Philadelphia.

The more important accessions of insects include the following: The Blackmore collection of Lepidoptera comprising about 7,000 specimens, of which 2,100 were recorded last year; about 600 South American insects collected by Edward Brundage; 75,000 miscellaneous insects transferred from the United States Bureau of Entomology and Plant Quarantine; the Charles R. Ely collection of Microlepidoptera—2,600 pinned specimens and 400 slides; a collec-

tion of 1,132 insects from the European Parasitic Laboratory in France; 14,000 miscellaneous specimens collected in western China by Dr. D. C. Graham; nearly 1,100 beetles from the British Museum; 15,000 Chrysomelidae from the Bowditch collection, by exchange with the Museum of Comparative Zoölogy; and valuable donations from the private collections of Father Edward Guedet (598 Lepidoptera and Coleoptera), A. B. Gurney (400 Ecuadorean Blattidae), and David G. Hall (3,700 muscoid flies).

The collections of marine invertebrates were notably augmented during the year by reason of the Presidential cruise of 1938 (more than 10,000 specimens) and the Bartlett Greenland expedition of 1938 (400 specimens). About 80,500 mollusks were added, including an important lot purchased through the Frances Lea Chamberlain fund and containing cotypes of 139 species of Chinese freshwater mussels of the Heude collection. About 40,000 mollusks were received from the Tennessee Valley Authority. The United States Biological Survey transferred 2,232 specimens of mollusks from Alaska.

About 50,500 plants were added to the herbarium collections, the largest lot being 11,000 specimens collected from little-known parts of Colombia by E. P. Killip of the Museum staff.

Geology.—Important additions to the mineralogical and petrological series were made possible by several Smithsonian funds. Among many purchased through the Roebling fund was a 153-pound topaz crystal from Brazil, as well as several rare minerals from classical European localities. Several fine suites came through the Canfield fund, the most important of which contains the finest phenacites, fluorites, aquamarines, and other minerals from Mount Antero, Colo. Through the auspices of the Chamberlain fund there were procured unusually cut specimens of topaz from Brazil and zircon from French Indochina. Forty-two meteorite specimens, 26 of which are credited to the Roebling fund, were added during the year. These represented 25 falls new to the Museum collection.

The largest and most important accession in the field of stratigraphic paleontology was the gift by John M. Nickles of his collection of Paleozoic fossils from the Ohio and Mississippi Valleys. This collection, containing about 10,000 specimens, largely bryozoan, represents many years of search and contains a wealth of excellent and carefully labeled material including many types. Two collections were made for the Museum by Dr. G. Arthur Cooper—one, numbering over 5,000 specimens, representing the Ordovician of the southern Appalachians, and the other comprising an equally large assemblage of Devonian fossils from the Hamilton group of the Catskill foothills in Pennsylvania.

Many fossil vertebrates, both mammalian and reptilian, were added as a result of a field expedition to Utah, including a nearly complete articulated skeleton of a new family of extinct lizard, a well-preserved skull of *Crocodilus*, and a complete shell of the turtle *Baena inflata*.

Engineering and industries.—In aeronautics the outstanding accession was a collection of relics of the aeronautical work of Samuel P. Langley, received as a deposit from the Smithsonian Institution. The material includes a catapult for launching flying-machine models, meteorological instruments, stuffed birds and birds' wings, propellers, engine parts, and many other devices used by Dr. Langley between 1894 and 1906 in his exhaustive researches in the field of mechanical flight. To the collection of aircraft engines was added an original and complete Union gasoline engine of the World War period, presented by Stanley H. Page. Several interesting models of historic Army and Navy airplanes were accessioned, as well as models of racing and commercial planes. Many miscellaneous objects pertaining to transportation, communication, metrology, mining and metallurgy, tools and crafts, medicine and public health, and chemistry continue to come in as gifts and loans, always welcome additions to these sections. To the graphic arts display many examples of fine bookmaking, photoengraving, printing, and photography were received, as well as some photographic and motion-picture equipment of value historically.

History.—Nearly 3,600 objects of historic and antiquarian interest were accessioned, including portraits, mementos, and medals of such American historic characters as Maj. Gen. Winfield Scott, Admiral George Dewey, George Sherman Batcheller, and Matthew Fontaine Maury. The numismatic collection was increased by 530 coins and medals and the philatelic collection by 2,598 foreign postage stamps, cards, and envelopes transferred from the Post Office Department.

EXPLORATIONS AND FIELD WORK

Scientific investigations in the field during the year were varied in kind and resulted in highly important additions to knowledge and in the contribution of many valuable specimens to the national collections. The work was financed principally by grants from the private funds of the Smithsonian aided by contributions from friends of the Institution.

Anthropology.—On August 25, 1938, Dr. Aleš Hrdlička, Curator of Physical Anthropology, completed his tenth season of work in Alaska and the Aleutian Islands. The sea transportation throughout these investigations was furnished by the United States Coast Guard, which deserves all credit for its active cooperation. The main ob-

jectives during this expedition were to verify the existence of a pre-Aleut stock, characterized by oblong-headed skeletons; to determine definitely whether the Commander Islands in the U. S. S. R. could have served as a second migration route for the coming of man from Asia; and to reexamine the burial caves on several islands of the Aleutian Chain. Rock shelters on Shiprock Island were first revisited, and several days were spent on the south shore of Amlia and the little island of Ilak. Three weeks were occupied in the excavation of pre-Aleut sites on Amchitka Island, and several more weeks were devoted to the extensive site near the village of Nikolski on the island of Umnak. A large series of skeletons was obtained, together with many bone and stone implements, large bone harpoon points, and several decorated ivory artifacts. From Umnak the expedition was transported on the Coast Guard vessel *Shoshone* to the Commander Islands, where the party spent 5 days. Dr. Hrdlička was able to examine all the more likely locations for prehistoric settlements. After careful examination of these sites, he was convinced that all dated from the Russian period, and the burials located were found to be those of Aleuts brought there in the early part of the nineteenth century by the Russians. No trace of pre-Russian habitations could be found on either Bering or Copper Islands. This substantiated the previous investigations of Dr. Leonhard Stejneger, who between 1882 and 1922 made several visits to the Commander Islands. During the return trip several stops were made at various islands in the Aleutian Chain. This year's explorations completed the present series in the Alaska work, begun by the Smithsonian Institution in 1926. The results will contribute substantial facts to more detailed investigations.

At the close of the fiscal year Dr. Hrdlička was visiting the U. S. S. R. by way of Europe in order to examine and study the skeletal material and associated material culture on exhibition in the various large museums. He was fortunte in finding sizeable collections made by the Russians from various sections of Siberia, which may contribute to his Alaskan research.

During September and October Dr. T. Dale Stewart, Associate Curator of Physical Anthropology, continued excavations at the Indian site on Potomac Creek in Stafford County, Va. In describing his trip up the Potomac River in 1608, Capt. John Smith stated that one of the Indian villages on the west shore, named Patawomeke, had 160 to 200 able men (upward of 1,000 inhabitants); it seems thus to have been the largest village along the river at the time, but there is little information regarding the village, and the date of its abandonment by Indians remains unknown. Inspection of Smith's map of the Potomac River, on which Patawomeke appears as a king's resi-

dence, shows that this village was situated on the north side of what is now Potomac Creek, near Marlboro Point. The Virginia land records indicate that the land constituting the "Potomac neck" was patented around the middle of the seventeenth century. About this time "Marlborough Town," with a courthouse, came into existence less than a mile away from the Indian site.

Archeologically the old Indian village site is important because of its known contact with the Jamestown colonists. No extensive excavations were undertaken, however, until 1935, when the late Judge William J. Graham became interested. Working intermittently during the next 2 years, until his death on November 10, 1937, Judge Graham succeeded in locating three large ossuaries, two small burial pits, and many post holes and trenches. From the largest ossuary and one of the small burial pits Judge Graham recovered European objects—glass beads, iron, copper, and a silver cup made at the beginning of the seventeenth century. In another ossuary he found what is probably the largest human skull yet recorded.

Following Judge Graham's death, and in accord with his wishes, his collections from Patawomeke and their accompanying records were presented to the National Museum. Early in 1938 permission was obtained to continue the investigation begun by Judge Graham. By the close of the season Dr. Stewart had determined the outlines of what is probably the main part of the Indian site. Located on a 30-foot bluff just above a spring that is still in use, the village was surrounded by one or more circular stockades. What appears to have been the inner stockade had a diameter of about 175 feet. He was not able to trace completely the outer concentric rows of post holes, but these may extend the diameter of the village to 280 feet or more. At the close of the present fiscal year Dr. Stewart resumed the excavations in order to complete as far as possible the outline of the famous stockaded village.

Dr. Waldo R. Wedel, Assistant Curator of Archeology, during July and August 1938 continued the archeological survey of Kansas. Scattered along the timbered bluffs of the Missouri River from its mouth to a point near St. Joseph, Mo., are groups of small mounds in which excavation has revealed stone enclosures containing burials. Their age, origin, and tribal identity have long resisted interpretation, though from the uniformity of construction it has been thought by some that they were left by a single people moving up or down the valley. Below the mouth of the Osage River such pottery and other materials as have been found in the chambers suggest affinities with remains usually termed "Woodland" in the eastern United States. Farther west there is less internal evidence, so that assignment of those in the Kansas City region to a given archeological

horizon had been well-nigh impossible. During the summer of 1937, however, Dr. Wedel's investigations in southern Platte County had disclosed village sites with artifacts evidently related to the Hopewellian complex of the upper Mississippi drainage; concurrently amateurs nearby reported the finding of similar pottery in a stone enclosure. With renewed hopes that some of the mystery surrounding these structures might finally be dispelled, excavations were resumed along the north bank of the Missouri between Parkville and Farley.

Nine enclosures were examined; all had been dug into previously and two were so hopelessly plundered as to give no reliable information. From the others it was established that the chambers vary from 6 to 9 feet across, are square to oval in outline, and range from 2 to nearly 4 feet deep. They consist of a carefully laid up mortarless wall of horizontal slabs, against which other large flat rocks were leaned. The area thus covered was about 15 feet in diameter. Two mounds yielded the dismembered skeletons of perhaps a dozen individuals, apparently of a medium-statured long-headed people. Artifacts were very rare and inconclusive, but it was noted that shell-tempered smooth and incised pottery occurred in portions of the structures which had been disturbed in prewhite days. Although direct proof is mostly lacking, it seems likely that the original structures in this vicinity were built by a people with Hopewellian affinities who were probably among the earliest potters and farmers in the eastern plains.

Near Farley, on the right bank of the Platte River, a prehistoric village and cemetery with different cultural connections was explored. Here the natives dwelt in earth-covered partly subterranean structures whose roofs were borne by four central posts. Shell-tempered pottery, often with incised lines, was abundant. Present also are small notched and unnotched points, scrapers, knives, drills, paired sandstone shaft-buffers, the polished adz or gouge, effigy pipes, fine-grained sandstone ornaments, bone awls, longitudinally pierced deer phalanges for cup-and-pin game, shell hoes, twisted cordage, maize, beans, pumpkin and sunflower seeds, and a few animal bones. In the nearby cemetery were more than 80 primary extended, bundle, and flexed burials, apparently of a short broad-headed population. Pottery generally indicates close relationships to that found on certain so-called middle Mississippi sites in southern Illinois and elsewhere.

On August 14, following intensive excavations in western Missouri, Dr. Wedel proceeded to Pueblo, Colo., to investigate caves reported to have disclosed traces of Indian occupancy. About 2 weeks were devoted to reconnaissance in the Purgatoire and tribu-

tary canyons, Las Animas County, and to brief inspection of several open sites in Baca County, heart of the "dust bowl," where three open camp sites were visited. From badly blown fields local collectors claim to have taken Folsom and Yuma artifacts and, in one instance, remains of an extinct camel. Miscellaneous flints, scrapers, knives, projectile points, and hammerstones were gathered, but nothing of demonstrably ancient date. On one site were small scattered piles of burnt and cracked stones; others showed black soil areas suggestive of hearths. All sites examined were near dry watercourses or on old dried-up shallow lake beds. In general it was found that (1) local rock shelters are mostly small and shallow, giving little promise of producing cultural remains as old as Folsom or Yuma are usually believed to be; (2) local collectors unanimously aver that such ancient remains are exceedingly rare in the cave and canyon country, though many occur in the sandy blown-out region from Baca County north; (3) occasional rock shelters do contain cultural vestiges, which, while apparently not geologically ancient, certainly merit careful scientific scrutiny before untrained excavators destroy the record. On June 8, 1939, Dr. Wedel returned to central Kansas to continue work of recovering an outline of the various prehistoric and historic Indian cultures.

Henry B. Collins, Jr., at the request of the National Park Service, spent a short time in checking the purported site of the former Chickasaw village of Ackia, near Tupelo, Miss. During this brief investigation he was able to verify the documentary records concerning this important village, which played an important role in the decisive battle of Ackia.

Biology.—The Presidential cruise of 1938 in the U. S. S. *Houston* resulted in the addition of important collections to the National Museum. At the invitation of President Roosevelt, Dr. Waldo L. Schmitt, Curator of Marine Invertebrates, served as naturalist on this cruise, which covered 5,888 miles in 24 days, from July 16 to August 9. Fourteen stops were made for fishing and scientific collecting, distributed in the territories of five different nations: Mexico (Baja California and Socorro Island); France (Clipperton Island); Ecuador (Galápagos Islands); Costa Rica (Cocos Island); and Colombia (Old Providence Island in the Caribbean). About 10,000 specimens were obtained, including 250 specimens of fishes representing 60 different species. More than 30 new species, subspecies, and varieties of animals and plants were discovered. Outstanding among them was a new genus and species of palm from Cocos Island, which was named *Rooseveltia franklíniana* by the describer, Dr. O. F. Cook, of the United States Department of Agriculture. Throughout the cruise the President took an active part and a lively interest in the collecting.

During April, at the invitation of Capt. G. Allan Hancock, Dr. Schmitt participated in a reconnaissance of the marine fauna of the north coast of South America and some of the adjacent islands. Stops were made in the Republic of Panama, Colombia, Venezuela, and the islands of Trinidad and Tobago, as well as at some of the smaller and lesser known islands in that region. A considerable collection of Crustacea and other marine forms was made. The macruran and anomuran crustaceans, about 7,000 in number, were brought back to the Museum for study and report.

As in past years, Capt. Robert A. Bartlett made a summer cruise to West Greenland and the adjacent Arctic regions. Captain Bartlett has always most generously cooperated with the Museum and has brought back from his cruises an extensive series of marine invertebrates and fish life from these northern waters. This year was no exception, and about 400 specimens came to the Museum as a result of the cruise. A commercial otter trawl was used successfully for collecting specimens not otherwise obtainable.

Dr. Alexander Wetmore, Assistant Secretary, collected in March and April in southern Veracruz, Mexico, and brought back valuable collections, principally birds, from this region whence the Museum has heretofore had little material. The work was entirely in the tropical lowlands, with a base at the archeological camp of M. W. Stirling near Tres Zapotes. W. M. Perrygo, H. Deignan, and G. Rohwer collected in Kentucky from September 15 to November 15, 1938, and obtained important material especially of mammals and birds. The work was renewed in the spring of 1939 when Perrygo and Rohwer spent about 3 months in the field in North Carolina.

Dr. Leonard P. Schultz, assisted by E. D. Reid, continued his study of the fresh-water fish fauna of Virginia by three field trips during the summer of 1938. Several rare and interesting species were collected and unexpected facts relating to geographical distribution were obtained.

Dr. Schultz left Washington on March 25, 1939, for an extended expedition to the South Pacific as naturalist on a naval vessel, the plan being to collect fishes and what other material time might permit. He had not returned at the close of the fiscal year.

Austin H. Clark continued a survey of the butterfly fauna of Virginia. Two forms new to the State were found during the last half of the summer of 1938 and a third in the spring of 1939. One species described from "Virginia" in 1789 was found in what is presumably the type locality after a lapse of 150 years. Many other interesting facts relating to distribution and habits were discovered.

E. P. Killip, Associate Curator of Plants, spent about 3½ months in Colombia from January to early May 1939, for the purpose of collecting in little-explored parts of that country in connection with

his work on the flora of Colombia. Members of the staff of the Colombian Institúto Botánico accompanied Mr. Killip on various excursions. Most of the time was spent in the Pacific lowlands, the regions visited including Gorgona Island, Bahia Solano, the Dagua Valley, and the upper San Juan River region in the heart of the Chocó. With Cali in the Cauca Valley as a base, several trips were made to the Western Cordillera. A few days were spent along the Quindío Trail, in the Central Cordillera, where special attention was given to the wax palms. Accompanied by A. H. C. Alston, of the British Museum (Natural History), Mr. Killip explored the region about Villavicencio in the Orinoco drainage basin; excursions were also made from Bogotá to various points in the Eastern Cordillera. Altogether, about 2,600 numbers of plants were collected, these including many duplicates.

Geology.—Dr. R. S. Bassler, Head Curator of Geology, during a vacation trip to England in August and September 1938, made certain researches in the well-known southern England fossil areas extending from Cornwall on the west to the Chalk Cliffs at Dover. Excursions were made to various parts of the English lowlands, with brief intervals spent at the British Museum (Natural History) to study and check formation and locality occurrences of Paleozoic crinoids. The field studies included particularly the Subcarboniferous limestone area near Bristol, a Mesozoic locality at Lyme Regis, and various chalk outcrops south and east of London. The most valuable result of the trip was the information obtained for more accurate labeling of the National Museum's collection.

In July 1938 Dr. G. A. Cooper, Assistant Curator of Stratigraphic Paleontology, went to Stroudsburg, Pa., and there met Dr. Bradford Willard, of the Pennsylvania Geological Survey, for paleontological work at various localities. They spent a week around Stroudsburg and in southeastern New York examining Devonian strata. Later Dr. Winifred Goldring, State paleontologist of New York, joined Dr. Cooper in a study of detailed sections of the Hamilton Group at Port Jervis and at various other localities between that city and Albany, N. Y. At Catskill, G. H. Chadwick joined the party. The object of the trip was to learn the sequence of strata in the Hamilton of eastern New York and to discover if possible the true top of the Hamilton in the Catskills southwest of Albany. All but the latter objective was attained. At the end of the New York work Dr. Cooper joined Dr. Willard in east-central Pennsylvania to study sections in the Hamilton and Tully strata. The entire work required about 6 weeks.

On May 2, 1939, Dr. Charles Butts and Dr. Cooper met Dr. Josiah Bridge, of the Geological Survey, in Bristol, Va., and from there continued to Montevallo, Ala. After studying Ordovician sections in

Alabama the party went on into Georgia for a few days, then to Chattanooga, Tenn. Following a week's work in eastern Tennessee, the men located for 10 days in Virginia to study the Ordovician rocks. Many fossils to be used in studies of the Chazyan brachiopods were collected.

Dr. E. O. Ulrich, Associate in Paleontology, made three trips partly under the auspices of the Geological Survey, but largely at his own expense, to forward his studies of Appalachian Valley Lower Paleozoic stratigraphy. These comprised a journey to Strasburg, Va., and vicinity in October 1938 and a 2 months' visit to the southern Appalachian Valley in the spring of 1939. This was followed by a short trip to the Appalachian Valley in Pennsylvania late in the fiscal year. All these investigations were highly satisfactory in the new stratigraphic information gained, as well as in checking doubtful problems of the past and in securing important collections.

C. W. Gilmore, Curator of Vertebrate Paleontology, accompanied by Dr. Remington Kellogg, Assistant Curator of Mammals, made a short trip to investigate reported cetacean discoveries along the York River, in southern Virginia, and along the Coneto River, near Tarboro, N. C. They found the cetacean remains at both of these localities to be very fragmentary.

Dr. C. L. Gazin, Assistant Curator of Vertebrate Paleontology, made an important expedition in the Cretaceous, Paleocene, and Eocene of Utah, which met with gratifying results. From the Upper Cretaceous of the North Horn region there were obtained additional remains of extinct lizards, including one articulated skeleton considered the most complete found in North America. From newly discovered Paleocene deposits about 50 additional specimens were obtained, including several new genera and species. From the Eocene of the Uinta Basin a representative mammalian collection was obtained, including a very fine skull and lower jaws of *Crocodilus*, as well as some good turtle specimens. These materials are an especially desirable addition to the Museum collections, which were previously weak in specimens from the Uinta formation.

MISCELLANEOUS

Visitors.—A total of 2,233,345 visitors were recorded at the various Museum buildings during the year. Though this number is 174,825 less than the previous year, it still represents a substantial increase over the number of visitors during the years following the economic decline of 1929. This year the high months were August 1938 and April 1939, when 320,746 and 337,892 visitors, respectively, were recorded. The attendance in the four Museum buildings was as follows: Smithsonian Building, 334,909; Arts and Industries Build-

ing, 1,016,048; Natural History Building, 709,139; and Aircraft Building, 173,249.

Publications and printing.—The sum of $24,000 was available during the year for the publication of the Museum Annual Report, Bulletins, and Proceedings. Thirty-five publications were issued—the Annual Report, 1 volume (vol. 6) of Bulletin 100 complete, 2 Contributions from the United States National Herbarium, 4 Bulletins, and 27 separate Proceedings papers. These made a total of 2,844 octavo pages and 283 plates, an increase of 1,404 pages and 41 plates over last year. The Bulletins issued were as follows: No. 170, Life Histories of North American Birds of Prey, Part 2, by Arthur Cleveland Bent; No. 172, Birds from Siam and the Malay Peninsula in the United States National Museum Collected by Drs. Hugh M. Smith and William L. Abbott, by J. H. Riley; No. 173, Catalog of the Mechanical Collections of the Division of Engineering, United States National Museum, by Frank A. Taylor; No. 174, Life Histories of North American Woodpeckers, by Arthur Cleveland Bent.

Volumes and separates distributed during the year to libraries and individuals throughout the world aggregated 69,658.

W. P. A. assistance.—The Works Progress Administration of the District of Columbia continued the assignment of workers to Museum offices, although during the course of the year the number decreased from 166 to 147. The service performed totaled 174,402 man-hours and embraced many types of work in all departments, such as checking, labeling, and repairing library material; preparing drawings and photographs; typing notes and records; model making and repair; preparing, mounting, cataloging, and labeling specimens; drafting; translating; computing; and repair of Indian pottery.

Special exhibitions.—Fourteen special exhibitions were held during the year under the auspices of various scientific, governmental, and educational agencies. In addition, the department of engineering and industries sponsored 23 special exhibits—3 in engineering, 8 in graphic arts, and 12 in photography.

CHANGES IN ORGANIZATION AND STAFF

A reorganization effective July 1, 1938, changed the designation of the former Department of Arts and Industries to Department of Engineering and Industries, and that of the Division of Textiles to Division of Crafts and Industries. On June 16, 1939, Dr. Wallace E. Duncan was appointed to this division as Assistant Curator of the Section of Chemical Industries. William C. Dawson was appointed scientific aid in the Division of Graphic Arts on June 1, 1939. In the Head Curator's office Miss Mary C. Wallace was advanced to clerk-stenographer on February 11, 1939.

In the Department of Anthropology the following personnel changes were made: Dr. Willard W. Hill was appointed on February 16, 1939, Associate Curator of Ethnology, to fill the position vacated by the transfer of Henry B. Collins, Jr., to the Bureau of American Ethnology. Dr. T. Dale Stewart was advanced to Associate Curator, Division of Physical Anthropology, on April 1, 1939.

In the Department of Biology Conrad V. Morton was advanced to Assistant Curator, Division of Plants, on March 16, 1939. Herbert G. Deignan was appointed to the Division of Birds as scientific aid on August 16, 1938. On October 1, 1938, Miss Marion F. Willoughby became senior scientific aid, Division of Stratigraphic Paleontology, Department of Geology. Miss Mary C. Breen, after serving as collaborator, Division of Mollusks, for nearly 29 years, resigned on February 13, 1939. Dr. Benjamin Schwartz was made honorary collaborator in the Section of Helminthology on February 8, 1939.

Other changes in staff and in personnel status among the Museum employees were as follows: Mrs. Dorothy Chamberlain was appointed senior clerk in the Associate Director's office to fill the vacancy caused by the resignation of Mrs. Margaret G. Shoup. In the editor's office, Miss Gladys O. Visel's designation was changed to editorial clerk on May 1, 1939. Michael Cahillane was appointed captain of guard and George F. Shaw lieutenant of guard on August 1, 1938, and William B. Stiles was made principal guard on January 7, 1939.

Eight employees were retired during the year under the Civil Service Retirement Act: Three for disability—Clark M. Braden, guard, on November 30, 1938; Mrs. Bessie L. Cartter, charwoman, on August 31, 1938; and Mrs. Eva M. Wright, charwoman, on March 11, 1939. Three on account of age—Clarence E. Bowman, guard, on July 31, 1938, with 17 years 2 months service; George W. Leonard, under mechanic, on July 31, 1938, with 16 years 2 months services; and Charles H. Chapin, guard, on May 31, 1939, with 15 years 4 months service. Two by optional retirement—George Johnson, captain of watch, on July 31, 1938, with 42 years 6 months service; and Mrs. Hattie J. Brady, attendant, on February 28, 1939, with 34 years service.

The Museum lost through death Glen E. Johnson, guard, on December 21, 1938, and two honorary workers long associated with its activities: Hugo Worch, custodian of the Section of Musical Instruments, on November 14, 1938, and B. Preston Clark, collaborator in the Division of Insects, on January 11, 1939.

Respectfully submitted.

ALEXANDER WETMORE, *Assistant Secretary.*

Dr. CHARLES G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 2

REPORT ON THE NATIONAL GALLERY OF ART

SIR: Pursuant to the provisions of section 5 (d) of Public Resolution No. 14, Seventy-fifth Congress, approved March 24, 1937, I have the honor to submit, on behalf of the Board of Trustees of the National Gallery of Art, the second annual report of the Board covering its operations for the fiscal year ended June 30, 1939.

Under the aforementioned joint resolution, Congress appropriated to the Smithsonian Institution the area bounded by Seventh Street, Constitution Avenue, Fourth Street, and North Mall Drive (now Madison Drive) Northwest, in the District of Columbia, as a site for a National Gallery of Art; authorized the Smithsonian Institution to permit The A. W. Mellon Educational and Charitable Trust, a public charitable trust, established by the late Hon. Andrew W. Mellon, of Pittsburgh, Pa., to construct thereon a building to be designated the "National Gallery of Art"; and created, in the Smithsonian Institution, a bureau to be directed by a board to be known as the "Trustees of the National Gallery of Art," charged with the maintenance and administration of the National Gallery of Art. The Board is comprised of the Chief Justice of the United States, the Secretary of State, the Secretary of the Treasury, and the Secretary of the Smithsonian Institution, ex officio, and five General Trustees. The General Trustees first taking office, appointed on June 24, 1937, by the Board of Regents of the Smithsonian Institution, were: the late Andrew W. Mellon, David K. E. Bruce, Duncan Phillips, the late S. Parker Gilbert, and Donald D. Shepard.

The late Andrew W. Mellon, the donor of the first great art collection given to the Gallery, as well as the funds for the erection of the Gallery building, died on August 26, 1937. Also, the late S. Parker Gilbert died on February 23, 1938. In August 1938 Paul Mellon was elected to serve the unexpired term of his father, the late Andrew W. Mellon; and Ferdinand Lammot Belin was elected to serve the unexpired term of the late S. Parker Gilbert. The following resolutions were adopted by the Board at its annual meeting held on February 13, 1939:

That the Board of Trustees of the National Gallery of Art, in recording the death on August 26, 1937, of Andrew William Mellon, founder of this Gallery and a member of this Board, express their profound sorrow at the loss of one

whose foresight and generosity were responsible for the establishment of this Gallery along lines truly national in scope; who, during the course of a long life of business activity and public service, found time to bring together the magnificent collection of art which, with the building now in course of erection and an endowment for future acquisitions, he has, with unparalleled generosity, given to his country for the benefit of all and "for the purpose of encouraging and developing a study of the fine arts." While he sought to efface himself in connection with the Gallery in order that others might be encouraged to contribute to this great national undertaking, he will not be forgotten but will always be remembered with gratitude by those who will benefit from what he has done, and his "story will live on, woven into the stuff of other men's lives."

That the Board of Trustees of the National Gallery of Art express their profound sorrow at the death on February 23, 1938, of Seymour Parker Gilbert, a Trustee of this Gallery, whose sound judgment and experience obtained during his years of public service peculiarly fitted him to be a useful and distinguished member of the Board. His loss will be greatly felt in this work as in many other fields of activitiy to which he gave generously of his time and strength.

At the annual meeting of the Board held February 13, 1939, Paul Mellon was elected President, and David K. E. Bruce was elected Vice President of the Board. Also, at this meeting Donald D. Shepard was elected a member of the executive committee, and Secretary Hull and David K. E. Bruce and Ferdinand Lammot Belin were elected members of the finance committee, Mr. Bruce to serve as vice chairman of the finance committee.

At a special meeting of the Board, held May 26, 1939, the Trustees adopted a seal and also passed appropriate resolutions relating to the administrative duties and responsibilities of officers of the Gallery. The Board accepted with regret the resignation of Paul Mellon as President, and elected David K. E. Bruce President to fill the vacancy thus occasioned, and also elected Ferdinand Lammot Belin Vice President to fill the vacancy in the office of Vice President occasioned by the appointment of Mr. Bruce as President. Donald D. Shepard was appointed General Counsel for the National Gallery of Art to serve in that capacity, in addition to his duties as Secretary and Treasurer of the Gallery. David E. Finley is serving as Director of the Gallery, having been elected to that position by the Board last year.

At an earlier meeting of the Board, held August 31, 1938, the Board appointed Harry A. McBride, of Pontiac, Mich., to fill the office of Administrator of the National Gallery of Art. Mr. McBride has served a number of years in the Foreign Service of the United States in an administrative and executive capacity, his last post being as Assistant to the Secretary of State. At the same meeting, John Walker, of Pittsburgh, Pa., was appointed Chief Curator of the National Gallery of Art. At the time Mr. Walker was serving as Associate in Charge of Fine Arts at the American Academy in

Rome. Stephen Pichetto, of New York City, well-known authority and expert in the restoration of art, was appointed on May 26, 1939, as consultant restorer of the National Gallery of Art.

On May 26, 1939, the General Trustees chose Joseph E. Widener, of Philadelphia, Pa., to fill the vacancy occasioned by the resignation of Paul Mellon as General Trustee to serve for the remainder of Mr. Mellon's term expiring July 1, 1947, and Samuel H. Kress, of New York, was elected and chosen as a General Trustee to serve until July 1, 1949, to succeed Donald D. Shepard, whose term was to expire July 1, 1939.

The most notable event of the year was the gift by Samuel H. Kress and the Samuel H. Kress Foundation of a collection of Italian paintings and sculpture, acclaimed by experts as one of the greatest private collections of Italian art in the world. In his letter of gift to the Board of Trustees of the National Gallery of Art, Mr. Kress said:

Over a period of many years, I have quietly acquired a collection of paintings and sculpture, particularly works of art representative of the Italian School, with the object of some day donating my collection to the public for exhibition and study in our country. Besides bringing from Europe as many as I could, I have made great effort to keep in this country paintings and sculpture that would otherwise very probably have been returned to Europe and have become permanently part of the great European galleries. I have done this in order that my Italian collection might include as many works as possible of the great Italian masters.

The collection includes important works of many of the outstanding masters of the Italian School, such as Giotto, Duccio, Simone Martini, Sassetta, Matteo di Giovanni, Neroccio, Fra Angelico, Masolino, Perugino, Filippo Lippi, Piero di Cosimo, Ghirlandaio, Gentile da Fabriano, Cossa, Mantegna, Giovanni Bellini, Giorgione, Titian, Tintoretto, and others; also sculpture by Desiderio da Settignano, Luca and Andrea della Robbia, Verrocchio, Rossellino, Benedetto da Maiano, Amadeo, Sansovino, and others.

I have followed with interest the establishment of the National Gallery of Art in Washington and the construction of the great edifice there to house the Nation's works of art. I have also noted with pleasure the Nation-wide interest exhibited in this Gallery, established by the late Andrew W. Mellon and dedicated to the encouragement and development of the study of the fine arts.

Because the Gallery and the works of art which it will contain will be for the benefit of all the people of the United States and will be accessible to so many citizens of this and other countries visiting our National Capital, it seems most suitable that others should contribute to the collection being formed there; and it is my wish, therefore, that the works of art which I have acquired should become part of the National Gallery Collection, and be exhibited in the gallery building now being erected in Washington. Realizing what it would mean to the Gallery at its opening, I decided some months ago that if the arrangements of the gift were satisfactory I would give up the pleasure of having possession of the collection in my home, and arrange to consummate the gift so that rooms may be prepared for the placing of the objects of art for the opening of the Gallery.

Following a letter from Mr. Kress to the President of the United States, advising him of the gift, President Roosevelt replied as follows:

My Dear Mr. Kress: Your decision to present to the people of the United States your priceless art collection is in keeping with the broad spirit of the Congress in establishing the National Gallery of Art, primarily as the home of the Mellon Collection. It has been the hope of those who have the welfare of the National Gallery at heart that other private gifts would supplement the treasures included in Mr. Mellon's Collection.

I am, therefore, most grateful for your letter of July 1st, in which you embody a letter to the Board of Trustees of the National Gallery of Art, setting forth the generous terms of your proposed gift. Not only are the treasures you plan to bestow on the Nation incalculable in value and in interest, but in their bestowal you are giving an example which may well be followed by others of our countrymen, who have in their stewardship art treasures which also happily might find a home in the National Gallery.

I feel that your proposed donation is a decided step in the realization of the true purpose of the National Gallery.

Very sincerely yours,

(Signed) Franklin D. Roosevelt.

The collection was gratefully accepted by the Board and will be installed in special rooms and settings before the formal opening of the Gallery. As can be seen from the list which is attached to this report, almost all the important Italian masters from the thirteenth through the eighteenth centuries are represented, and in the opinion of experts no other private collection and very few museums can illustrate in so complete a manner as Mr. Kress' collection the development of the Italian school of painting during the Renaissance period. Indicating the high value placed on the Kress collection by experts in the field of art, Sir Kenneth Clark, Director of the National Gallery of Art in London, made the following observation after seeing the collection:

There can be no doubt that it is one of the most remarkable collections of fourteenth and fifteenth century Italian art ever formed. It is very comprehensive, containing masters hardly represented in any other American collection; and Mr. Kress has managed to assemble a number of real masterpieces of a kind one had supposed no longer available.

Other well-known authorities and experts, such as Dr. Wilhelm Suida, Count Contini Bonacossi, of Florence, Prof. Roberto Longhi, F. Mason Perkins, and Bernard Berenson have all publicly praised the quality and scope of this magnificent collection.

The paintings and sculpture in the Kress collection will be exhibited in such a way as to show both the growth of the different schools—Florentine, Sienese, Central Italian, North Italian, and Venetian—and the chronological development of Italian art as a whole. With Mr. Kress' collection and the paintings and sculpture donated by Mr. Mellon, the National Gallery will immediately become a center for the

study of art in the United States, and one of the great galleries in the world.

There were no other acquisitions during the year. Other works of art were offered as gifts, but were not accepted because in the opinion of the Board they were not considered desirable for the Gallery.

During the year the Board loaned the following paintings from the Mellon collection to the Masterpieces of Art Exhibition at the New York World's Fair for the period April 30 to October 31, 1939: Rembrandt's "Self Portrait"; Hals' "An Old Woman Seated"; and Terborch's "A Gentleman Greeting a Lady"; also the following paintings from the Mellon collection to the Golden Gate International Exposition at San Francisco, for the period February 1 to December 31, 1939: Rembrandt's "A Young Man at Table"; Hals' "Portrait of Balthasar Coymans"; Pieter de Hoogh's "A Dutch Courtyard."

During the year the act of March 24, 1938, providing for the construction and maintenance of the National Gallery of Art, was amended by Congress by Public Resolution No. 9, Seventy-sixth Congress, approved April 13, 1939, so as to authorize the appropriation of public funds, prior to the completion of the Gallery building, for administrative and operating expenses and equipment preparatory to the opening of the Gallery to the public. Under this authorization, the budget of the National Gallery of Art, insofar as public funds for the fiscal year 1940 are concerned, after approval by the Board at its annual meeting on February 13, 1939, was submitted to Congress and the sum of $159,000 for the above purposes was appropriated, the amount being included in the Act approved June 30, 1939.

Under this appropriation, the Board immediately proceeded to establish temporary offices for the Gallery in quarters furnished by The A. W. Mellon Educational and Charitable Trust. A nucleus of the permanent staff was employed on July 1, 1939. This staff will be engaged in preparatory work in the compilation of catalogs for the Gallery, in working with the Civil Service Commission on the classification of positions for the complete permanent staff, in the purchase of furniture and supplies to be placed in the Gallery building upon its completion, and in setting up the accounting systems required by the Board and by Government regulations. This preparatory work will enable the Board to expedite the opening of the Gallery to the public as soon as the building is completed and the collections arranged therein.

Work on the building and construction of the Gallery is proceeding rapidly, the superstructure being practically completed. It is hoped

that the construction of the building will be far enough advanced by August 1, 1940, so as to permit the installation of the collections preparatory to the public opening.

As of June 30, 1939, $5,350,920.07 had been expended by The A. W. Mellon Educational and Charitable Trust upon the construction of the building, which, it is estimated, will cost in excess of $15,000,000. The recording of such expenditures in the books of account of the National Gallery of Art will be deferred until the completion of the construction of the Gallery.

No appropriations made by Congress for the National Gallery of Art were expended during the fiscal year ended June 30, 1939, and no public or private funds were received or disposed of during the year. Pursuant to instructions, Price, Waterhouse & Co., a nationally known firm of public accountants, has made an examination of the accounting records of the National Gallery of Art, and a copy of the certificate of that firm dated September 8, 1939, follows:

Pursuant to your instructions, we have made an examination of the accounting records of the National Gallery of Art and other documentary evidence, and have obtained information and explanations from its officers.

The books of account reflect the acquisition as of June 24, 1937, of the works of art donated by The A. W. Mellon Educational and Charitable Trust, valued for accounting purposes at $31,303,162.31. Pursuant to joint resolution of Congress and the trust indenture, The A. W. Mellon Educational and Charitable Trust, at its expense, is proceeding with construction of the National Gallery of Art. The recording of the construction expenditures in the books of account of the National Gallery of Art is being deferred until completion of construction. An endowment fund of $5,000,000 is expected to be received from The A. W. Mellon Educational and Charitable Trust at about the time of completion of the Gallery.

By an indenture effective June 29, 1939, Mr. Samuel H. Kress and the Samuel H. Kress Foundation donated certain works of art to the National Gallery of Art subject to completion of construction of the Gallery building on or before June 29, 1941. The value for accounting purposes of the works of art so acquired has not yet been determined and no entries in respect of this gift have yet been recorded in the books of account.

Our examination disclosed no other transactions to June 30, 1939, which should be recorded in the books of account.

Our examination did not include inspection of the works of art to which the National Gallery of Art had title at June 30, 1939. We have, however, examined the deeds of trust by the donors which provide that the donors shall be responsible for the custody and shall bear the cost of storage and insurance until delivery of the works of art is made after completion of the Gallery building.

In our opinion, based upon our examination, the books of account, subject to the fact that no entry has been made in respect of the works of art acquired June 29, 1939, fairly present, in accordance with accepted principles of accounting consistently maintained by the Gallery during the year under review, the position of the National Gallery of Art at June 30, 1939.

PAINTINGS AND SCULPTURE CONTAINED IN THE COLLECTION GIVEN TO THE NATIONAL GALLERY OF ART BY SAMUEL H. KRESS AND THE SAMUEL H. KRESS FOUNDATION

PAINTINGS

Sandro Botticelli	Crucifixion.
Ridolfo Ghirlandaio	Portrait of Taddeo Taddei.
Provincial Follower of Piero della Francesca.	Madonna Enthroned.
Ugolino da Siena	Madonna and Child.
Giovanni di Niccolo da Pisa	Madonna and Child.
Giambattista Tiepolo	Child Moses Trampling Upon the Crown of the Pharaohs.
Antonio Vivarini	St. Catherine Knocking Down the Idols.
Pseudo-Boccaccino	A Saint.
Do	A Saint.
School of Mantegna	Triumph of Religion.
Do	Triumph of Time.
Do	Triumph of Mortality.
Do	Triumph of Love.
Do	Triumph of Fame.
Do	Triumph of Death.
Niccolo di Pietro Gerini	Four Saints Before a King.
Benedetto Bembo	St. John Preaching.
Vittore Carpaccio	Prudentia.
Lombard School or Zavataro	Madonna, Child, Saints, and Donor.
Lippo Memmi	Madonna and Child.
Moretto da Brescia	Madonna, Child, and Saints.
Vittore Carpaccio	Temperentia.
Follower of Pietro Lorenzetti	Crucifixion.
Giovanni Paolo Pannini	Interior of the Pantheon.
Luca di Tomme	Crucifixion.
Paolo di Giovanni Fei	Calvary.
Sienese School	A Saint.
Do	A Saint.
Bartolommeo Montagna	Madonna and Child.
Bernardino Pintoricchio	Madonna and Child.
Giulio Bugiardini	Portrait of a Young Girl.
Domenico Morone or Parenzano ?.	Adoration of the Wise Men.
Antonio da Saliba	Madonna and Child.
Pietro di Domenico da Montepulciano.	Coronation.
School of Orcagna	Coronation.
Carlo Crivelli	Two Saints.
Jacopo di Cione	Madonna, Child, and Saints.
Bartolommeo di Giovanni	Tribute to Apollo.
Do	A King with His Wise Men.
Andrea di Bartolo	Presentation at Temple.
Do	Birth of the Virgin.
Do	Giving of Alms by Gioacchino.
Vincenzo Catena	Portrait of a Girl.
Sano di Pietro	Crucifixion.

PAINTINGS—continued

Giovanni Battista Piazzetta	Sleeping Shepherdess.
Mariotto di Nardo	Crucifixion.
Bronzino (Alessandro Allori)	Portrait of a Youth.
Sano di Pietro	St. Benedict.
Do	St. Augustine.
North Italian or Tomasso da Modena.	St. Jerome in His Study.
Martino di Bartolommeo or Taddeo di Bartolo.	Holy Saint.
Maestro di San Pietro Ovile	St. Mary Magdalen.
Martino di Bartolommeo	Crucifixion.
Marco and Sebastiano Ricci	Ruins and Figures.
Girolamo Genga	St. Agostino Clothes the Three Catechumen.
Gualtieri di Giovanni	Madonna and Child.
Florentine School	Miracle of St. Nicholas.
Bronzino (Alessandro Allori)	Portrait of a Boy.
Paris Bordone	Diana and Nymphs.
Moretto da Brescia	St. Jerome Penitent.
Giovanni Maria Crespi (G. M. Crespi).	Cupids with Sleeping Nymphs.
Pietro Longhi	The Simulated Faint.
Do	Blind Man's Buff.
Fra Bartolommeo and Mariotto Albertinelli.	Madonna, Child, and Saints.
Rosalba Carriera	Portrait of a Boy.
Giambattista Tiepolo	The Virtuous One.
Do	Woman with Parrot.
Angelo Puccinelli	Predella.
Agnolo Gaddi	Annunciation with Donor.
Sebastiano Ricci	St. Francis of Paolo Resuscitates a Boy.
Do	St. Helen Finds the Real Cross.
Francesco Francia	Madonna and Child.
Jacopo Tintoretto	Aurora.
Matteo di Giovanni or Cozzarelli.	Madonna and Child Between Two Angels.
Piero di Cosimo or Other	Madonna, Child, Saints, and Angels.
Rosello di Jacopo Franchi	Cassone Front.
Francesco Salviati	Portrait of a Young Woman.
Pontormo (Jacopo Carrucci)	Portrait of a Young Man.
Michele Giambono	St. Peter.
Giusto de Menabuoi	St. Paul and St. Augustine.
Paolo di Giovanni Fei	Madonna and Child between Two Angels, St. Francis and St. Ludwig.
Correggio (Antonio Allegri)	Marriage of St. Catherine.
Bernardo Daddi	Flagellation.
Do	A Holy Martyr.
Giovanni da Milano	St. Anthony Abbot.
Rimini Artist (follower of Giotto).	Crucifixion with Mary and John.
Domenico Feti	Banquet of Epulone.
Master of the Rucellai Polyptych.	Polyptych.

PAINTINGS—continued

Alegretto Nuzi	Resurrection of Drusiana.
Do	St. John and Philosopher Cratone.
Do	St. John Converts Azzio and Cugio.
Do	St. John Drinks Poison.
Bernardino Licinio	Portrait of a Musician.
Bonifazio Veronese	Holy Conversation.
Lorenzo Lotto	Portrait of a Man.
Filippino Lippi	St. Francis in Glory.
Dosso Dossi	Portrait of Man with Flag.
Franciabigio	Portrait of a Young Man.
Giambattista Tiepolo	Apotheosis of a Poet.
Garofalo (Benvenuto Tisi)	Baptism of Christ.
Vittore Ghislandi	Portrait of a Young Man.
Paolo Schiavo	Flagellation of Christ.
Ugolino da Siena	Christ Blessing.
Guadenzio Ferrari	The Manger.
Matteo Balducci	Venus and Cupid.
Pietro Rotari	Half Figure of Girl Asleep.
Do	Half Figure of Girl with Flower in Hair.
Francesco Pesellino	Crucifixion and Two Saints.
Giambattista Tiepolo	Portrait of a Youth.
Andrea Vanni	Adoration of the Magi.
Andrea di Giusto	Assumption.
Francesco Guardi	Bridge with Three Arches.
Giovanni Battista Moroni	Portrait of a Gentleman in Adoration before the Madonna.
Francesco del Cossa	Madonna, Child, and Angels.
Vittore Carpaccio	Holy Family.
Lorenzo Lotto	St. Catherine.
Bartolommeo Vivarini	Madonna and Child.
Bernardino Fungai	The Miracle of the Oxen.
Bernardino Luini	Venus.
Follower of Angelico and Benozzo.	Madonna, Child, and Angels.
Dido Master	Triumphal Train of a Queen.
Canaletto	View of the Ducal Palace.
Neri di Bicci	Five Saints.
Spinello Aretino	Madonna, Child, Angels, and Saints.
Jacopo Bassano	Annunciation to the Shepherds.
Giovanni del Biondo	Madonna and Child, St. John the Baptist, and St. Catherine.
Agnolo Gaddi	Madonna with Child, Saints, and Angels.
Francesco Guardi	Campo San Zanipolo.
Andrea da Firenze	Crucifixion.
Giovanni Baronzio	Baptism of Christ.
Jacopo Tintoretto	The Trinity Courted by the Angels.
Sebastiano Mainardi	Madonna with the Child, St. John, and Three Angels.
Cenni di Francesco	Madonna and Child.
Andrea di Giusto	Judgment Scene.
Rosalba Carriera	Allegory of Painting.
Florentine Master, about 1420.	Cassone Front.

PAINTINGS—continued

Benedetto Diana	Holy Family.
Pietro Lorenzetti	Madonna, Child, and Saints.
Domenico Veneziano	Stigmatization of St. Francis.
Duccio di Buoninsegna	Calling of Peter and Andrew.
Giorgione?	Venus and Cupid in Landscape.
Paolo Veneziano	Crucifixion.
Marco Basaiti	Madonna and Child.
Fra Angelico da Fiesole	St. Francis and St. Dominic.
Lorenzo Vecchietta	Pieta.
Lorenzo Lotto	Maiden's Dream.
Master of the Melzi Madonna.	Madonna and Child between St. Bartholomew and St. John Baptist.
Vittore Carpaccio	St. Nicolas.
Do	St. Peter Martyr.
Jacopo di Cione	Dead Christ with Mary, St. John, and Donor.
Bernardino Luini	Madonna and Child.
Giovanni Battista Utili (Biagio di Antonio)	Cassone Front.
Giovanni dal Ponte	Triptych.
Pietro Perugino	The Annunciation.
Lorenzo Lotto	Allegory.
Jacopo Tintoretto	Portrait of Young Man in White.
Paolo Veronese	The Assumption.
Michelangelo Caravaggio	Still Life.
Piero di Cosimo	Allegory.
Francesco Ubertini called Bacchiacca.	Allegorical Tondo.
Taddeo di Bartolo	Madonna and Child.
Sano di Pietro	Listed as The Annunciation (actually Madonna in Adoration with Saints and Angels).
Giovanni Bazzani	Mythological Scene.
Federico Baroccio	Woman with Book.
Bernardino Zenale	Virgin and Saints.
Jacopo del Sellaio	Adoration of the Magi.
Cima da Conegliano	St. Jerome in the Wilderness.
Antoniazzo Romano	Crucifixion.
Lorenzo Costa	A Saint.
Do	A Saint.
Do	A Saint.
Do	A Saint.
Pseudo-Pier Francesco Fiorentino.	Madonna and Child.
Lattanzio da Rimini	Madonna and Child.
Marco Basaiti	Madonna and Child.
Cimabue?	Capture of Christ in the Garden.
Andrea Mantegna	Judith and Her Servant.
Giovanni Battista Utili (Biagio di Antonio).	Portrait of a Boy.
Jacopo Tintoretto	Worship of the Golden Calf.
Francesco Guardi	Sacred Family.
Giovanni Bellini	Portrait of a Man.
Mariotto di Nardo	Madonna, Child, and Saints.

PAINTINGS—continued

Bramantino (Bartolommeo Suardi).	Madonna and Child.
Francesco Salviati	Portrait of a Young Man
Jacopo Tintoretto	Nativity.
Filippino Lippi	A Saint.
Do	A Saint.
Jacopo Tintoretto	Apollo and Marsyas.
Guiseppe Bazzani	Laughing Man.
Tanzio da Varallo	St. Sebastian.
Pontormo (Jacopo Carrucci)	Portrait of a Medici.
Vittore Carpaccio	St. Stephen.
Do	St. John Baptist.
Francesco Francia	Madonna, Child, and St. John.
Vincenzo Catena	Portrait of a Man.
Giovanni Boccatis	Portrait of a Monk.
Giovanni Battista Moroni	Portrait of a Man.
Geolamo Bedoli-Mazzola	Portrait of a Monk.
Cimabue?	Last Supper.
Pietro Perugino	Pieta.
Bartolommeo di Giovanni	Epiphany.
Agnolo Gaddi	Coronation.
Antonello da Saliba	Abraham's Meeting with the Angels.
Giovanni Bellini	Portrait of a Man.
Albertino Piazza da Lodi	Madonna Surrounded by Angels.
Maestro Esiguo	Crucifix.
Lippo Vanni	Predella.
Vittore Crivelli	St. Francis.
Bernardino Fungai	A Saint.
Leonardo Scaletti	Madonna and Child.
Paolo Veronese	Baptism of Christ.
Titian	Cupid with Wheel of Fortune.
Alesso Baldovinetti	Madonna and Child.
Pietro Perugino	Madonna and Child.
Simone Martini	Announcing Angel.
Giovanni Bellini	St. Jerome Reading.
Carrand or Barberini Master.	The Annunciation.
Ercole Roberti	Portrait of Giov. II Bentivoglio.
Do	Portrait of Ginevra Bentivoglio.
Domenico Venezziano	Madonna and Child.
Neroccio de'Landi	Madonna and Child with St. Jerome and St. Mary Magdalen.
Giovanni di Paolo	The Annunciation.
Giovanni Bellini	Portrait of Condottiere Bartolommeo Colleoni.
Masolino da Panicale	Annunciation (Angel).
Do	Annunciation (Madonna).
Francesco del Cossa	St. Liberale.
Do	St. Lucy.
Filippino Lippi	Tobias and the Angel.
Moretto da Brescia	Portrait of Lady in White.
Jacopo Tintoretto	Susanna.
Bartolommeo Vivarini	Coronation.
Filippino Lippi or Sellaio	Bust of Christ.

PAINTINGS—continued

Sodoma (Giov. Ant. Bazzi)	Leda.
Correggio (Antonio Allegri)	Portrait of a Young Girl.
Giovanni da Bologna	Coronation.
Antonio Veneziano	St. Paul.
Ambrogio da Predis	Madonna and Child.
Pisan School	Scene from Life of Christ.
Giovanni di Paolo	Polyptych.
Neroccio de'Landi	Naval Battle of Actium.
Francesco di Giorgio	Visit of Cleopatra to Mark Antony.
Fra Filippo Lippi or Fra Diamante.	Two Saints.
Do	Two Saints.
Correggio?	Madonna of the Carnation.
Stefano di Giovanni Sassetta	Madona, Child, and Holy Father.
Pellegrino di Mariano	Triptych.
Jacopo del Casentino	Presentation at the Temple.
Pietro Lorenzetti or Ugolino Lorenzetti.	A Female Saint.
Dosso Dossi	Departure of the Argonauts.
Lippo Memmi	Madonna and Child.
Domenico Morone	Madonna and Ecce Homo.
Lorenzo Costa	St. Paul.
Giovanni Bellini	Portrait of a Young Man.
Gentile da Fabriano	Madonna and Child.
Giotto	Madonna and Child.
Bartolommeo Veneto	Portrait of Maximilian Sforza.
Giorgione and Titian	A Venetian Gentleman.
Titian	A Lady at Mirror.
Fra Angelico da Fiesole	The Entombment.
Nardo di Cione	Madonna and Child with Sts. Peter and John Evangelist.
Giovanni Bellini	The Virgin and Child.
Jacopo Bellini	Profile Portrait of a Boy.
Carlo Crivelli	Madonna and Child.
Benozzo Gozzoli	St. Ursula and Donatrice with Angels.
Andrea Mantegna	Madonna and Child.
Francesco Pesellino	Madonna and Child.
Gentile da Fabriano	Miracle of St. Nicolas of Bari.
Domenico Ghirlandaio	St. Michael.
Do	St. Dominic.
Marco Zoppo	St. Peter.
Paolo Uccello and Assistants	Battle Scene.
Jarvis Master	Triumph of Chastity.
Sano di Pietro	Madonna, Child, and Angels.
Vincenzo Foppa	St. Christopher.
Luca Signorelli	Birth of St. John.
Barnaba da Modena	Madonna, Child, and Five Saints.
Matteo di Giovanni	Judith.
Fra Filippo Lippi	Nativity.
Pietro Perugino	St. Jerome in the Wilderness.
Luca Signorelli	Life of St. Niccolo.
Giovanni di Paolo	Assumption of the Virgin with Two Saints.

PAINTINGS—continued

Jacopo del Sellaio	St. John in the Wilderness.
Lorenzo Costa	Apostles at Death of Virgin.
Do	Miracle of the Catafalque.
Do	Apostles at Death of the Virgin.
Fra Filippo Lippi or Fra Diamante	Two Saints.
Lorenzo Lotto	Nativity.
Giorgione	Adoration of the Shepherds.
Fra Filippo Lippi	Madonna and Child.
Simone Martini	St. John.
Titian	Portrait of Giulia di Gonzaga.
Stefano di Giovanni Sassetta.	Meeting of St. Anthony and St. Paul.
Pintoricchio	Portrait of a Youth.
Cosimo Rosselli	Madonna and Child with Saints.
Fra Filippo Lippi	Head of Madonna.
Matteo di Giovanni	Madonna, Child, and Saints.
Paolo Uccello?	Madonna and Child.
Master of the Louvre Predellas.	Annunciation.
Lorenzo Veneziano	Madonna and Child.
Barnaba da Modena	Crucifixion.
Master of the Virgil Codex	Madonna, Child, and Angels.
Amico Aspertini	St. Sebastiano.
Francesco di Giorgio	Cassone Front.
Sodoma (Giov. Ant. Bazzi)	Madonna, Child, and St. John.
Francesco Granacci	Madonna, Child, and St. Joseph.
Giannicolo di Paolo	Crucifixion.
Cariani (Giov. Busi)	Portrait of a Gentleman.
Gentile da Fabriano	Madonna, Child, and Angels.
Giovanni Boccatis	Madonna and Child.
Alvise Vivarini	St. Jerome.
Follower of Giotto	Crucifixion.
Domenico di Michelino	Seven Sciences.
Do	Seven Virtues.
Bernardino Pintoricchio	Madonna and Child.
Francesco di Antonio Banchi.	Madonna and Child.
Pietro Perugino	St. Bartholomew.
Benvenuto di Giovanni	Christ in the Garden.
Cosimo Rosselli	Holy Family and Angels.
Neri di Bicci	Life of St. Appolonia.
Niccolo di Pietro Gerini	Madonna and Child.
Vincenzo Catena	Christ and the Samaritan.
Andrea Vanni	St. Clara.
Girolamo del Pacchia	Madonna and Child.
Borgognone (Ambrogio Fossano).	Madonna and Child.
Francesco Granacci	Cassone Painting.
Alvise Vivarini	St. Jerome.
Do	St. John Baptist.
Gianpietrino	Portrait of a Lady as Magdalen.

PAINTINGS—continued

Ugolino Lorenzetti	The Crucifixion.
L'Ortolano	Presentation at the Temple.
Domenico Beccafumi	Cassone Front.
Sodoma (Gio. Antonio Bazzi).	St. Sebastian and Saints.
Giovanni Bellini	Virgin and Child.
Girolamo di Benvenuto	Portrait of a Lady.
Vittore Carpaccio	Lady Reading.
Giovanni Bellini	Portrait of a Man.
Andrea del Sarto	Madonna, Child, and Infant St. John.
Cosimo Tura	Portrait of a Man.
Cosimo Rosselli or Ghirlandaio.	Madonna and Child.
Giovanni Baronzio	Adoration of the Magi.
Luca di Tomme	Madonna and Child with Saints and Angels.
Piero di Cosimo	The Visitation.
Bernardino Luini	The Nativity.
Giovanni Battista Utili (Biagio di Antonio).	Nativity with Saints and Donor.
Bernardo Daddi	Madonna and Child with Saints.
Giambattista Tiepolo	Timocleia and the Thracian Commander.
Guariento	Madonna, Child, and Four Saints.
Vincenzo Foppa	Madonna and Child.
Lorenzo di Niccolo	Crucifixion with Four Saints.
Giovanni di Paolo	Saint Luke.
Giacomo Pacchiarotto	Madonna and Child.
Piero di Cosimo	Nativity with St. John.
Girolamo Romanino	Madonna and Child.
Pietro Degli Ingannati	Female Saint.
Fra Bartolommeo	Creation of Eve.
Sienese School (perhaps Niccola di Segna)	St. Margarete.
Girolamo di Santa Croce	Annunciation.
Fra Bartolommeo and Fra Paolino.	Madonna, Child, and Saints.
Giovanni Antonio Pordenone	St. Christopher.
Franciabigio	Madonna and Child.
Garofalo (Benvenuto Tisi)	St. Jerome in the Desert.
Paris Bordone	Venus at the Forge of Vulcan.
Girolamo da Carpi	Assumption of the Virgin.
Alessandro Magnasco	Landscape with Figures.
Vincenzo Civerchio	St. Peter.
Giovanni Francesco Caroto	Deposition of Christ.
Pellegrino di Mariano	Small Altarpiece.
Pontormo (Jacopo Carrucci)	Holy Family.
Dosso Dossi	St. Lucretia.
Alessandro Magnasco	Storm at Sea.
Maestro del Bambino Vispo	Adoration of the Magi.
Girolamo da Treviso	Madonna and Child.
Mariotto Albertinelli	Madonna and Child.
Giovanni del Biondo	Annunciation.

SCULPTURE

Giovanni Antonio Amadeo	Marble Angel.
Do	Marble Angel.
Do	Marble Madonna and Child.
Andrea Sansovino	Marble Madonna and Child.
Francesco di Simone Ferrucci	Marble Tondo: Madonna and Child.
Pierino da Vinci	Marble Profile of Woman.
Desiderio da Settignano	Marble Bust of Isotta da Rimini.
Antonio Rossellino	Marble Relief: Madonna and Child.
Benedetto da Maiano	Marble Relief: Nativity.
Andrea della Robbia	Glazed Majolica: St. Peter.
Luca della Robbia	Glazed Majolica: Madonna and Child.
Andrea della Robbia	Glazed Majolica: Head of Boy.
Do	Glazed Majolica: Head of Boy.
Andrea del Verrocchio	Terra Cotta: Adoration.
Tomassao Fiamberti	Marble Relief.
Tino da Camaino	Marble Relief: Madonna and Child.
Zuan Zorzi Lascari or other (called Pirgotele).	Marble Relief: Madonna, Child and Saints.
Annibale Fontana	Terra Cotta: Adoration.

Respectfully submitted.

DAVID K. E. BRUCE, *President.*

DR. C. G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 3

REPORT ON THE NATIONAL COLLECTION OF FINE ARTS

SIR: I have the honor to submit the following report on the activities of the National Collection of Fine Arts for the fiscal year ended June 30, 1939:

The gallery of the National Collection was closed for renovation during the last 4 months of the year and will probably be reopened in the autumn of 1939. Tons of weak plaster have been replaced, and the woodwork is being painted to match the light-colored monk's cloth with which the walls are to be covered. This monk's cloth is "air-conditioned" in that it is backed with rubber to prevent the irregular collection of dirt which has been the major fault of loosely woven, light-colored fabrics as wall coverings. The appearance of the gallery will be greatly improved, and the collections will be seen to much better advantage.

APPROPRIATIONS

For the administration of the National Collection of Fine Arts by the Smithsonian Institution, including compensation of necessary employees, purchase of books of reference and periodicals, traveling expenses, uniforms for guards, and necessary incidental expenses, $34,275 was appropriated. This amount was reduced $750, bringing it to $33,525, of which $16,542 was expended for the care and maintenance of the Freer Gallery of Art, a unit of the National Collection of Fine Arts. The balance of $16,983 was spent for the care and upkeep of the National Collection of Fine Arts, nearly all of this sum being required for the payment of salaries, traveling expenses, books, periodicals, and necessary disbursements for the care of the collections.

THE SMITHSONIAN ART COMMISSION

The eighteenth annual meeting of the Smithsonian Art Commission (formerly the National Gallery of Art Commission) was held on December 6, 1938. The members met at 10:30 in the Natural History Building, where, as the advisory committee on the acceptance of works of art which had been submitted during the year, they accepted the following:

Wash drawing on cardboard entitled "The Devil's Tower from Johnstons," by Thomas Moran (1837–1926). Gift of the estate of John Holme Maghee, through Mrs. John P. Marble, Chevy Chase, Md.

A Mourning Pin, by an unknown artist. Gift of Edmund Bury, Philadelphia, Pa.

Statues of J. Q. A. Ward (1830–1910) and Joseph Jefferson (1829–1905), by Charles H. Niehaus (1855–1935). Gift of the sculptor's daughter, Miss Marie J. Niehaus, Grantwood, N. J. "The Driller," by Charles H. Niehaus, was in very bad condition, but the members of the Commission granted permission to have it repaired and exhibited.

Bronze bust of Andrew Furuseth (1854–1938), by Ivan Mestrovic (1883–). Gift of Charles R. Crane, New York, N. Y.

The members then proceeded to the Smithsonian Building, where the annual meeting was called to order by the chairman, Mr. Borie. The members present were Charles L. Borie, Jr., chairman; Dr. Charles G. Abbot (ex officio), secretary; Herbert Adams, Gifford Beal, John E. Lodge, David E. Finley, Frederick P. Keppel, Paul Manship, George B. McClellan, and Mahonri M. Young. Ruel P. Tolman, Curator of the Division of Graphic Arts in the United States National Museum and Acting Director of the National Collection of Fine Arts, was also present.

The following resolutions on the death of Mr. Edmund C. Tarbell were submitted and adopted:

Whereas the Smithsonian Art Commission has learned of the death, on August 1, 1938, of Edmund C. Tarbell, a member of the Commission since 1924; therefore be it

Resolved, That the Commission desires here to record its sorrow at the loss of Mr. Tarbell, who was highly respected and valued alike for his exceptional ability as a painter, for his keen judgment regarding works of art, and for his deep and helpful interest in the affairs of the Commission.

Resolved, That these resolutions be entered upon the records of the Commission and that the Secretary be requested to communicate them to the family of Mr. Tarbell.

The resignation of Charles Moore was submitted and accepted with regret. The chairman appointed Dr. Abbot to communicate an expression of the regret of the Commission to Mr. Moore.

The Commission recommended to the Board of Regents the name of Louis Ayres to fill the vacancy caused by the death of Mr. Tarbell, and that of Gilmore D. Clarke to fill the vacancy caused by the resignation of Mr. Moore.

It also recommended to the Board of Regents the reelection of Herbert Adams and Gifford Beal for the succeeding term of 4 years.

The following officers were reelected for the ensuing year: Charles L. Borie, Jr., chairman; Frank Jewett Mather, Jr., vice chairman; and Dr. Charles G. Abbot, secretary.

The following were reelected members of the executive committee for the ensuing year: Herbert Adams, and George B. McClellan (Charles L. Borie, Jr., as chairman of the Commission, and Dr.

Charles G. Abbot, as secretary of the Commission, are ex officio members of the executive committee). Mr. McClellan was elected chairman, and Mr. Clarke was elected to serve in place of Mr. Moore.

Dr. Abbot reported in detail the meetings of the Smithsonian Gallery of Art Commission, and a discussion followed relative to the proposed plans and site for the Smithsonian Gallery of Art.

Mr. Finley made a report on the progress of the National Gallery of Art building and invited the members of the Commission to view the Mellon collection at the Corcoran Gallery of Art during the afternoon.

THE CATHERINE WALDEN MYER FUND

Two miniatures were acquired from the fund established through the bequest of the late Catherine Walden Myer, as follows:

Miniature of Mary White, wife of Governor John Willis Ellis of North Carolina, by J. Henry Brown (1818–1891); from Mrs. Sue Bruner Clontz, Salisbury, N. C.

Miniature of Polly Sutton Catlin (1770–1844), mother of George Catlin, by George Catlin (1796–1872); from Miss Marion Lane, Washington, D. C.

LOANS ACCEPTED

A mourning miniature by an unknown artist (about 1804) was lent by Mrs. Mary Koolage House, Lansdowne, Pa.

Three family portraits by unknown artists of Elizabeth Ann Kimberly, Capt. Patrick Kavanagh, and Charles Washington Kavanagh and William McK. Kavanagh, were lent by Mrs. Noble Newport Potts, Washington, D. C.

LOANS TO OTHER MUSEUMS AND ORGANIZATIONS

Upon the request of the Icelandic Government, the plaster model for the statue of Leifr Eiricsson, by Alexander Stirling Calder, was dismantled by Attilio J. Contini, New York City, and taken by him by truck to E. Gargani & Sons, Brooklyn, N. Y., for the purpose of making a bronze cast to be exhibited at the New York World's Fair. (Returned April 15, 1939, and assembled by Mr. Contini.)

"Sunset, Navarro Ridge, California Coast," by Ralph A. Blakelock, was lent to the Golden Gate International Exposition for inclusion in the Department of Fine Arts from February 18 to December 2, 1939.

"Cliffs of the Upper Colorado River, Wyoming Territory," by Thomas Moran, was lent to the Carnegie Institute, Pittsburgh, Pa., from March 22 to April 30, 1939. (Returned May 8, 1939.)

"Lower Ausable Pond," by Homer D. Martin, and "September Afternoon," by George Inness, were lent to The Museum of Modern Art Gallery of Washington, D. C., for an exhibition of American paintings, from March 5 to April 2, 1939. (Returned April 3, 1939.)

"Friendly Neighbors," by Alfred C. Howland, was lent to Harvard University, William Hayes Fogg Art Museum, Cambridge, Mass., for an exhibition of New England genre by New England artists, from May 15 to September 1, 1939.

Upon the request of J. V. Herring, of Howard University, the paintings "Portrait of a Lady," by Gilbert Stuart; "Georgia Pines," by George Inness; and "Moonlight," by Albert P. Ryder, were lent to Bennett College, Greensboro, N. C., for an exhibition of American paintings to be shown at the opening of their new library building on April 16, 1939. (Returned May 15, 1939.)

A bronze statute of Lincoln, by Augustus Saint Gaudens, was lent, with the consent of the owners, the estate of Mrs. John Hay, to the New York World's Fair for exhibition in the Illinois Building. A pedestal was also lent.

The Procurement Division of the United States Treasury, through Robert LeFevre, borrowed, with the consent of their owner, William Kemeys, of Garrett Park, Md., the following three pieces of sculpture by Edward Kemeys: "Fighting Panther and Deer"; "Bronze Wolf" (No. 3); and "Bronze Wolf" (No. 4). A plaster statue "Grizzly Bear," by Edward Kemeys, the property of the Smithsonian Institution, and a blue Sevres vase, No. 371 from the Pell collection, with a wooden base, were also selected for use in the State reception suite at Union Station.

WITHDRAWALS BY OWNERS

A bronze statue "Negro Mother and Child," by Maurice Glickman, lent in 1934 by the Public Works of Art Project, was withdrawn April 15, 1939, and sent to the New York World's Fair for exhibition.

THE HENRY WARD RANGER FUND

Approval of the loan of "Margery and Little Edmund," by Edmund C. Tarbell, was given the Museum of Fine Arts, Boston, Mass., for an exhibition of the work of Frank W. Benson and the late Edmund C. Tarbell, from November 15 through December 15, 1938. The painting had been purchased in 1929 by the Council of the National Academy of Design from the fund provided by the Henry Ward Ranger Bequest and had been assigned to The Grand Rapids Public Library, Grand Rapids, Mich.

THE NATIONAL COLLECTION OF FINE ARTS REFERENCE LIBRARY

A total of 524 publications were accessioned during the year. A card index of auction prices brought by works of art was begun, which when completed, will save many hours of search now made necessary by the frequent requests for information on the market value of art objects.

SPECIAL EXHIBITIONS

The following exhibitions were held:

July and August 1938.—The Eberstadt collection of 260 naval historical prints, lent by the Naval Historical Foundation, was continued through August.

September 3 to 26, 1938.—Architectural exhibition of representative buildings of the post-war period, consisting of 127 photographs assembled by the Committee on Education, American Institute of Architects, lent by the American Federation of Arts.

October 7 to 30, 1938.—Special exhibition of 200 prints by graphic artists, Federal Art Project, Works Progress Administration.

November 8 to 29, 1938.—Special exhibition of 76 water-color paintings of the flora of the Isthmus of Panama, by Marie Louise Evans, under the patronage of His Excellency, the Minister of Panama, Señor Dr. Don Augusto S. Boyd.

January 6 to 30, 1939.—Special exhibition of 173 framed water-color sketches and 7 progressive proofs of wild flowers of various National Parks, by Mary Vaux Walcott.

February 3 to 27, 1939.—Special exhibition of 56 oil paintings, 38 drawings, 4 water colors, and 3 pastels, by Joel J. Levitt (1875–1937).

PUBLICATIONS

Tolman, R. P. Report on the National Collection of Fine Arts for the year ended June 30, 1938. Appendix 3, Report of the Secretary of the Smithsonian Institution for the year ended June 30, 1938, pp. 35–40.

Lodge, J. E. Report on the Freer Gallery of Art for the year ended June 30, 1938. Appendix 4, Report of the Secretary of the Smithsonian Institution for the year ended June 30, 1938, pp. 41–45.

Respectfully submitted.

R. P. Tolman, *Acting Director.*

Dr. C. G. Abbot,
Secretary, Smithsonian Institution.

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APPENDIX 4

REPORT ON THE FREER GALLERY OF ART

SIR: I have the honor to submit the nineteenth annual report on the Freer Gallery of Art for the year ended June 30, 1939:

THE COLLECTIONS

Additions to the collections by purchase are as follows:

BRONZE

38.20. Chinese, early Chou dynasty, (1122–947 B. C.). A ceremonial vessel of the type *kuei* (or *chiu* or *tui*). Pale yellow bronze with a thin, scattered malachite and cuprite patination inside and out. Inscription of 11 characters inside. 0.278 by 0.341 over all; base 0.198 by 0.187. (Illustrated.)

39.5. Chinese, late Chou dynasty, middle fifth century B. C. A large basin of the type *chien*. White bronze with an even, pale green patination sprinkled with granular encrustations. Inscription of six characters inside. 0.227 by 0.518 over all. (Illustrated.)

JADE

39.6–39.34. Chinese, Shang (Yin) and late Chou dynasties, twelfth to third century B. C. Twenty-nine carved jades. (39.16, 39.29, 39.30 illustrated.)

MANUSCRIPT

38.19. Arabic (Egypt), fifteenth century. The 18th *juz'* of the *Qur'ān*. The text is written in black *thuluth* script with additions in red, five lines to a page, on 48 paper leaves, sewed. Four illuminated head-pieces; illuminated verse-stops and marginal marks. 0.370 by 0.263 (average leaf).

PAINTING

38.18. Chinese, dated in correspondence with A. D. 1369. Ming dynasty. By Sung K'o. Bamboo. Ink on paper. Signature and seal. Forty-three other seals *plus* one on the label. Three inscriptions. Makimono: 0.249 by 0.981.

39.1. Chinese, dated in correspondence with A. D. 1552. Ming dynasty. By Wên Pi (Chêng-ming), 1470–1567. A river landscape. In ink and transparent color on paper. Nineteen seals on the picture proper; 30 seals on the mount. Title and colophon written and signed by the artist. Makimono: 1.415 by 0.305.

39.2. Chinese, Ming dynasty. By Shên Chou, 1427–1509. A river landscape. In ink and transparent color on paper. Inscription with signature and 9 seals on the picture proper; 6 inscriptions and 36 seals on the mount. Makimono: 1.690 by 0.248.



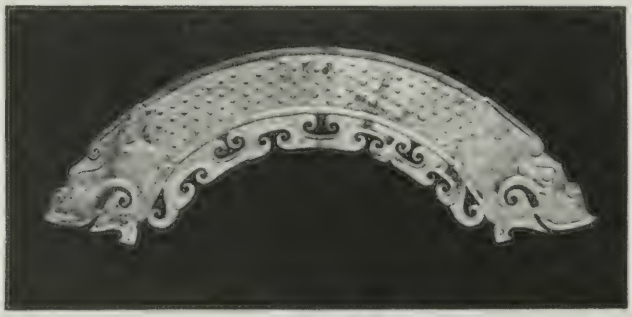
38.20

39.5

SOME RECENT ADDITIONS TO THE COLLECTION OF THE FREER GALLERY OF ART.



39.16



39.29



39.30

SOME RECENT ADDITIONS TO THE COLLECTION OF THE FREER GALLERY OF ART.

39.3. Chinese, dated in correspondence with A. D. 1554. Ming dynasty. By Lu Chih, 1495–1576. A river landscape in spring. In ink and transparent color on paper. Signature and 4 seals on the painting; 3 inscriptions and 10 seals on the mount. Makimono: 1.001 by 0.223.

39.4. Chinese, sixteenth century, Ming dynasty. By Ch'iu Ying, fl. 1522–1560. A mountain landscape. In ink and color on paper. Inscription with the artist's signature and 14 seals on the painting; 2 labels, 8 inscriptions and 35 seals on the mount. Makimono: 3.067 by 0.254.

39.35–
39.36. East Indian, fifteenth century. Two illustrations upon leaves taken from a manuscript of the *Mārkaṇḍeya-pūraṇa*. In outline drawing and solid color upon palm leaf. Palm leaves: 0.051 by 0.238; paintings each 0.051 by 0.065.

Curatorial work during the past year has been devoted to the study of the new acquisitions listed above and to other Chinese, Japanese, Arabic, Persian, East Indian, and Armenian manuscripts or art objects, either already in the permanent collection or submitted for purchase. Other Chinese, Japanese, Arabic, Persian, Egyptian, Byzantine, American, and European objects were sent or brought to the Director by their owners requesting information as to identity, provenance, quality, date, inscription, and so on. In all, 1,386 objects and 586 photographs of objects were so submitted, and written or oral reports upon them were made to the institutions or the private owners who requested this service. Written translations of 17 inscriptions in Oriental languages also were made upon request.

Changes in exhibition have involved a total of 71 objects, as follows:

Chinese bronze mirrors	12
Chinese bronze vessels	6
Chinese gold	4
Chinese jade	2
Chinese painting	32
Chinese silver	2
Chinese silver-gilt	6
Persian pottery	7

ATTENDANCE

The Gallery has been open to the public every day from 9 until 4:30 o'clock, with the exception of Mondays, Christmas Day, and New Year's Day.

The total attendance of visitors coming in at the main entrance was 102,813. One hundred twenty-three other visitors on Mondays makes the grand total 102,936. The total attendance for week-days, exclusive of Mondays, was 76,682; Sundays, 26,131. The average week-day attendance was 295; the average Sunday attendance, 523. The highest monthly attendance was reached in April, 14,483; the lowest in January, 5,449.

There were 1,602 visitors to the main office during the year. The purposes of their visits were as follows:

For general information		378
To see objects in storage		393
Far Eastern paintings	92	
Tibetan paintings	1	
Near Eastern paintings and manuscripts	15	
East Indian paintings and manuscripts	9	
American paintings	61	
Whistler prints	6	
American pottery	2	
Oriental pottery, jade, bronzes, sculptures	149	
Syrian, Arabic, and Egyptian glass	2	
Gold Treasure and Byzantine objects	3	
Washington Manuscripts	53	
To read in the library		188
To make tracings and sketches from library books		2
To see building and installation		39
To obtain permission to photograph or sketch		4
To examine or purchase photographs		364
To submit objects for examination		187
To see members of the staff		225
To see the exhibition galleries on Mondays		51

LECTURES AND DOCENT SERVICE

On Wednesday, March 15, 1939, an illustrated lecture upon "Essentials in Chinese Painting" was given by Dr. Osvald Sirén, Curator of Oriental Arts, National Museum, Stockholm. The audience numbered 221.

Upon request, 16 groups, ranging from 8 to 26 persons (total 260) were given instruction in the study room, upon Chinese Arts, or upon new acquisitions. Two groups, of from 6 to 17 persons (total 23) were given instruction in the pottery storage room, and 6 groups, ranging from 9 to 290 persons (total 392) were given docent service in the exhibition galleries.

The Smithsonian Gallery of Art Commission held three of its meetings in the study and staff rooms.

PERSONNEL

Miss Eleanor Thompson was married on September 7, 1938, to Capt. James Snedeker, United States Marine Corps.

Edmund O. Mueller, of Fort Atkinson, Wis., was appointed as painter on February 8, 1939.

Changes in the daily watch force were as follows:

C. E. Bowman, retired, July 31, 1938.
C. H. Gardner, transferred to the United States Employees Compensation Commission, as junior audit clerk, on August 1, 1938.
William P. Bennett, appointed to the force, August 24, 1938.
E. A. Altizer, appointed September 2, 1938.

Grace T. Whitney worked intermittently at the Gallery between October 14, 1938, and June 30, 1939, on translations of Persian texts.

Respectfully submitted.

J. E. Lodge, *Director.*

Dr. C. G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 5

BUREAU OF AMERICAN ETHNOLOGY

SIR: I have the honor to submit the following report on the field researches, office work, and other operations of the Bureau of American Ethnology during the fiscal year ended June 30, 1939, conducted in accordance with the act of Congress of May 23, 1938, which provides "For continuing ethnological researches among the American Indians and the natives of Hawaii and the excavation and preservation of archeologic remains. . . ."

SYSTEMATIC RESEARCHES

M. W. Stirling, Chief, left Washington on December 24 to begin archeological excavations at a large site near the village of Tres Zapotes in southern Veracruz. This work was undertaken in cooperation with the National Geographic Society, which financed the expedition. The permission to conduct the work was obtained earlier in the year from the Mexican Department of Public Education, whose generous cooperation greatly facilitated the work. With Dr. C. W. Weiant as assistant, excavations were begun on January 1 and continued until April 15.

Although detailed results of this first season of work cannot be announced until further study has been made of the material, far-reaching connections are indicated which require careful study of the Maya, Zapotec, Huastec, and Teotihuacan areas. Nine major stone monuments were excavated at the site, including the famous "Cabesa Colosal," and a very large collection of ceramics and figurines was obtained. The most interesting discovery was a stone monument inscribed with an initial-series date. This is in a style closely related to that on the Tuxtla statuette and apparently records a late Baktun 7 date.

At the conclusion of the work the collections were brought to Mexico City where a division was effected with the Mexican Government. A large carved stone box and the dated monument were sucessfully transported to the National Museum in Mexico City.

The greater part of the year was devoted by Dr. John R. Swanton, ethnologist, to work connected with the researches of the United States De Soto Expedition Commission. During most of October and the first half of November 1938, he was in the field in the interest of that

Commission. Visits were made by automobile to points in North and South Carolina and southern Georgia, and a great deal of time was spent in researches in Florida, where he was assisted materially by Dr. Herman Gunter, the State geologist, and J. Clarence Simpson. On leaving Florida, Dr. Swanton visited Dr. Walter B. Jones, member of the Commission from Alabama, at Tuscaloosa, and then went to Aberdeen, Miss., where he was met by Col. John R. Fordyce, the Commissioner from Arkansas. In company with Colonel Fordyce and Dr. W. A. Evans, of Aberdeen, he visited several points in northern Mississippi. Colonel Fordyce then drove him to Helena, Ark., where 2 days were spent in the examination of sites along Crowley's Ridge and on White River. Afterward excursions were made to the Menard Mounds near Little Rock and points along the Little Missouri River. On October 26 Dr. Swanton and Colonel Fordyce joined Miss Caroline Dormon, the Louisiana member of the Commission, and her sister, at Jonesville, La., and spent 2 days on the Ouachita and Tensas Rivers in launches kindly furnished by the Mississippi River Commission and accompanied by some of the Commission's officials. Later Dr. Swanton visited Baton Rouge to confer with members of the geological staff of the Louisiana State University, and with James A. Ford, the archeologist engaged in research work in that State, returning from there to Little Rock and thence to Washington.

The remainder of the calendar year 1938 was devoted to the completion of the report of the Commission, and during the first months of 1939 Dr. Swanton was engaged in reading proof for this report, which appeared in May as House Document No. 71 of the Seventy-sixth Congress. It covers 400 pages and includes 11 maps.

On May 30, by special invitation, Dr. Swanton attended the unveiling of a marker at Shaw's Point, near Bradenton, Fla., commemorative of the landing of De Soto, and during this trip he spoke to audiences at Rollins College, Winter Park, on the Indians of Florida and the work of the De Soto Commission, and before the Kiwanis Club at Bradenton and the Jacksonville Historical Society at Jacksonville on the latter subject.

On December 29, 1938, Dr. Swanton delivered the retiring address as president of section H of the American Association for the Advancement of Science.

The start of the fiscal year found Dr. John P. Harrington, ethnologist, engaged in a study of the northern provenience of the Navaho. This tribe, the largest single-dialect Indian population in the United States, numbering some 50,000 souls, centers its present habitat in eastern Arizona and western New Mexico and speaks an aberrant form of Western Apache. It is patent that Western Apache, and also

Eastern Apache (represented by Kiowa Apache, Jicarilla Apache, and Lipan) are tongues of northern origin, coming from beyond the present northern boundary of the United States, the language-bearing ancestors of these so-called Navaho and Apache peoples having migrated from the north. This migration was far back of the range of history, and the reason for accepting this migration is found in the existence of the surprisingly closely related Athapascan languages occupying all the interior of Alaska and western Canada, a patch near the mouth of the Columbia, and another taking in much of the southern Oregon and northern California coast region.

The study of the northern origin of the Navaho consisted of the assembling of documentation from historical and ethnological sources, interviewing of Indians, and discussions with archeologists and ethnologists engaged in Siberian, Alaskan, Great Basin, High Plains, and Navaho region investigations.

The nearest linguistic sisters of the Navaho language in the north are the Carrier and closely related Chilcotin of the southernmost part of the Northern Interior Plateau mentioned above, and east of them the Sarcee, in the Rockies and the plains just east of the Rockies.

The Smithsonian Institution having come into possession of an unprinted source giving a first-hand account of the Sacramento Valley Indians of California in 1850, including two vocabularies of native Indian languages, from the pen of Prince Paul, educated German traveler and friend of Sutter, the founder of Sacramento, Calif., Dr. Harrington left in May to check this new and important material with native informants. The source consisted of an account of the natives of the "Hok" farm, belonging to Sutter. Dr. Harrington discovered the old Indian rancheria mound called "Hok" on the west edge of the Feather River 7 miles south of Yuba City.

July 1 found Dr. Frank H. H. Roberts, Jr., archeologist, in camp at the Lindenmeier site, north of Fort Collins, in northern Colorado, continuing his excavations in search of additional information on Folsom man, the aboriginal nomad who hunted bison, mammoth, and the American camel on the western plains during the closing stages of the glacial period. The work was carried on until the end of September when digging was stopped for the season. During the course of the summer's investigations 3,500 square feet of the original surface of occupation was uncovered. The overburden ranged from 3 to 8 feet in depth so that a considerable quantity of earth had to be removed before the stratum containing the desired archeological record was reached. Included in the layer were various concentrations of cut and split animal bones, most of them from the extinct *Bison taylori*, several hearths, places where the stone chippers had made their tools from different kinds of material present in the vicinity, and an assort-

ment of implements. The collection of specimens of the people's handicraft obtained from the season's excavations comprises, in addition to typically fluted points and a series of tools similar to those found in previous years, several new types of stone knives and scrapers and a number of bone fragments bearing portions of simple, incised, geometric decorations. This material serves to broaden the knowledge on the material culture complex characteristic of this group of early American peoples. The digging also produced important evidence on the relation between the occupation level and certain geologic deposits and helped confirm the correlation of the site with definite features dating from the late glacial horizon in that general area.

After the termination of the work at the Lindenmeier site, Dr. Roberts visited places in Nebraska, Wyoming, and Saskatchewan, Canada, where local collectors have found objects attributable to the Folsom or some other, presumably associated, complex. The sites in Nebraska are in the southwestern corner of the State in Chase and Dundy Counties. The locations inspected in Wyoming are in the northeastern part of the State in the vicinity of Sundance. The Saskatchewan sites are near Mortlach and are of interest because they extend the range of this type of material well toward the north along the postulated route of migration of peoples coming from Asia into the New World. From Mortlach, Dr. Roberts returned to Washington and resumed his office duties on November 1.

During the winter months galley and page proofs were read and corrected for the report, Archeological Remains in the Whitewater District, Eastern Arizona, Part I, House Types, which appeared as Bulletin 121 of the Bureau of American Ethnology. Manuscript for the second part of this report, describing the artifacts and burials associated with the house remains, was revised, completed, and transmitted to the editor for publication in the bulletin series. An article, The Folsom Problem in American Archeology, which appeared in the book Early Man, as depicted by leading authorities at the International Symposium at the Academy of Natural Sciences, Philadelphia, March 1937, was revised, augmented with new information and a series of illustrations, and otherwise made suitable for use in the appendix to the Annual Report of the Board of Regents of the Smithsonian Institution for 1938. In addition several short papers on archeological subjects were written for various anthropological journals. Information on Old World archeology was furnished for a radio broadcast on the subject Pushing Back History, and this and several other scripts for "The World is Yours" program were read and checked for errors.

In March the Honorable Cordell Hull, Secretary of State, appointed Dr. Roberts to represent the United States on the International Commission for Historic Monuments.

On June 9, 1939, Dr. Roberts left Washington for Colorado, where he resumed excavations at the Lindenmeier site. By the end of the fiscal year he had opened up another portion of the site and was obtaining further data on the Folsom problem.

Dr. Julian H. Steward, anthropologist, spent the months of July and August 1938 in continuing an archeological and ethnological reconnaissance in western South America which was begun during the preceding fiscal year. During this period several Indian villages of the highlands were visited, and a number of archeological sites were examined in both the highland and coastal regions. These researches were undertaken as a preliminary to the editing of the projected Handbook of South American Indians, and on his return to Washington Dr. Steward began preparation of the final plans for the Handbook. These plans were completed during the remainder of the fiscal year, and the project has now been initiated, various contributors having been invited to participate.

Scientific papers prepared by Dr. Steward during the past year are: Anthropological Reconnaissance of Southern Utah, for a Bureau of American Ethnology Bulletin; Anthropological Reconnaissance in South America, for Explorations and Field-Work of the Smithsonian Institution in 1938; Some Observations on Shoshonean Distributions, for the American Anthropologist; The Economic Basis of Changes in the Shoshonean Indian Culture, for the Scientific Monthly; Notes on Hillers' Photographs of the Paiute and Ute Indians taken on the Powell Expedition of 1873, for the Smithsonian Miscellaneous Collections.

Henry B. Collins, Jr., was appointed ethnologist in the Bureau, effective February 1, 1939, by transfer from the Division of Ethnology, United States National Museum. From February 1 to the end of the fiscal year Mr. Collins spent the greater part of his time working over the large and varied collection of artifacts, numbering several thousand specimens, which he excavated in 1936 at Cape Prince of Wales and other prehistoric Eskimo sites in the immediate vicinity of Bering Strait. A statement of the activities of Mr. Collins during the preceding part of the fiscal year is included in the report of the Department of Anthropology of the United States National Museum.

Dr. William N. Fenton, ethnologist, joined the staff of the Bureau of American Ethnology on February 6, 1939, coming to the Bureau from St. Lawrence University. He will continue ethnological studies among the Iroquois groups in New York and Canada with the aim of cleaning up some of the ethnological problems in the

northeastern area that remain from the research of previous students. The Rosenwald Fund of Chicago financed a field trip to the Senecas at Coldspring on the Allegany Reservation in southwestern New York during the interim that followed the end of the first semester at the University and preceded removal to Washington. Dr. Fenton wrote up his field notes on the Seneca Midwinter Festival as a supplement to notes taken in 1934, as soon as he was established at the Bureau. In April and May, Dr. Fenton wrote a monograph on Iroquois Suicide from cases collected during 1935, as a member of the United States Indian Field Service, and parallel cases that occur in the earlier ethnological and historical sources on the Iroquois. He submitted the manuscript for publication in June before leaving for the field. Another manuscript, Tonawanda Longhouse Ceremonies: Ninety Years After Lewis Henry Morgan, written in 1936 and recently rewritten, was submitted for publication at the same time.

SPECIAL RESEARCHES

Miss Frances Densmore, a collaborator of the Bureau, in continuation of her study of Indian music, submitted two manuscripts entitled "Choctaw War and Dance Songs" and "Choctaw and Seminole Songs," with phonograph records and transcriptions of 31 Choctaw and 9 Seminole songs. The Choctaw songs were recorded near Philadelphia, Miss., in January 1933, and the Seminole songs were recorded at Brighton, Fla., in February of the same year. Transcriptions and phonograph records of two performances on a Choctaw flute were also submitted. These flutes were played by medicine men during ball games to bring success to one group of players and confuse their opponents. Robert Henry, who recorded the flute playing, is a leading medicine man at the ball games. The 66 Choctaw songs, now in possession of the Bureau, were listed according to their catalog numbers. Fourteen manuscripts on the music of the Winnebago, previously submitted, were combined in one manuscript and retyped preparatory to publication, the retyped material comprising about 300 pages. The 205 Winnebago songs were arranged in final order, and listed according to serial and catalog numbers. The galley and page proof, also the music proof, of Nootka and Quileute Music were read during the year.

During the fiscal year ended June 30, 1939, John G. Carter, a collaborator of the Bureau, devoted considerable time to the ethnographic and Indian sign-language material contained in the manuscripts of the late Maj. Gen. Hugh L. Scott, United States Army. These manuscripts, together with other material, were donated to the Bureau by the widow of General Scott. The material donated consisted of newspaper clippings, pamphlets and other printed matter, photographs, and manuscript.

This material was examined, read, and classified. The photographs were turned over to their proper custodian in the Bureau for filing and record. The pamphlets and other printed matter were disposed of in like manner. The manuscript was read and classified in separate filing jackets. Many historical references in these manuscripts were checked for accuracy.

An extensive research was made into the writings of most of the early discoverers and explorers of the North American continent, beginning with the Norsemen, in order to determine the extent to which and the localities in which the sign language was used by the North American Indians. It was ascertained, as far as the records which have been examined to date reveal, that the sign language was confined to the buffalo-hunting tribes of the plains west of the Mississippi River, and to tribes adjacent to the plains who made seasonal hunts into the buffalo country. This confirms the statements made by General Scott in his manuscripts.

EDITORIAL WORK AND PUBLICATIONS

The editing of the publications of the Bureau was continued through the year by Stanley Searles, editor.

BULLETINS ISSUED DURING THE YEAR

118. An Archaeological Survey of the Norris Basin in Eastern Tennessee, by William S. Webb.

119. Anthropological Papers, Nos. 1–6. No. 1, A Preliminary Report on Archeological Explorations at Macon, Ga., by A. R. Kelly. No. 2, The Northern Arapaho Flat Pipe and the Ceremony of Covering the Pipe, by John G. Carter. No. 3, The Caribs of Dominica, by Douglas Taylor. No. 4, What Happened to Green Bear Who Was Blessed With a Sacred Pack, by Truman Michelson. No. 5, Lemhi Shoshoni Physical Therapy, by Julian H. Steward. No. 6, Panatübiji', an Owens Valley Paiute, by Julian H. Steward.

120. Basin-Plateau Aboriginal Sociopolitical Groups, by Julian H. Steward.

121. Archeological Remains in the Whitewater District, Eastern Arizona. Part I, House Types, by Frank H. H. Roberts, Jr.

122. An Archaeological Survey of Wheeler Basin on the Tennessee River in Northern Alabama, by William S. Webb.

123. Anthropological Papers, Nos. 7–12. No. 7, Archeological Investigations in the Corozal District of British Honduras, by Thomas and Mary Gann. No. 8, Linguistic Classification of Cree and Montagnais-Naskapi Dialects, by Truman Michelson. No. 9, Sedelmayr's Relacion of 1746, translated and edited by Ronald L. Ives. No. 10, Notes on the Creek Indians, by J. N. B. Hewitt, edited by John R. Swanton. No. 11, The Yaruros of the Capanaparo River, Venezuela, by Vincenzo Petrullo. No. 12, Archeology of Arauquin, by Vincenzo Petrullo.

IN PRESS

101. War Ceremony and Peace Ceremony of the Osage Indians, by Francis La Flesche.

124. Nootka and Quileute Music, by Frances Densmore.

125. Ethnography of the Fox Indians, by William Jones, edited by Margaret Welpley Fisher.

The Index to Schoolcraft's Indian Tribes has been completed. Publications distributed totaled 19,527.

LIBRARY

The library continued under the direction of Miss Miriam B. Ketchum, librarian. Accessions during the year totaled 223.

The exchange list has been completely revised and brought up to date, and seven new exchange sets have been added.

The rare book section was finished early in the fiscal year, and the rarest items and many others of importance have been shelved in it. More than half of these books have been recataloged and classified and permanently labeled and shelved.

All the publications of North American societies and institutions have been sorted and all matter not in the field of the Bureau discarded as far as possible.

The librarian attended the meetings of the Inter-American Bibliographical and Historical Society at Washington, D. C., in February, and the Special Libraries Association at Baltimore in May.

The usual routine work of accessioning and cataloging new material and entering new periodicals received has been kept up to date.

ILLUSTRATIONS

Following is a summary of work accomplished by E. G. Cassedy, illustrator:

Topographic surveying	1
Plates prepared	94
Line drawings	114
Photographs retouched	44
Lettering jobs	126
Graphs	12
Maps	18
Mechanical drawings	2
Engrossing jobs	1
Total	412

COLLECTIONS

Accession No.

148,708. Potsherds, figurine fragments, and other artifacts from various sites in Mexico, collected in 1938 by M. W. Stirling for the Bureau. (51 specimens.)

152,153. Male skeleton from deep trench west of Mound A, Shiloh National Monument, Tenn., and a miscellaneous archeological collection, obtained in the course of excavations conducted by F. H. H. Roberts, Jr., during the winter of 1933–34 in cooperation with the Civil Works Administration.

MISCELLANEOUS

During the course of the year information was furnished by members of the Bureau staff in reply to numerous inquiries concerning the North American Indians, both past and present, and the Mexican peoples of the prehistoric and early historic periods. Various specimens sent to the Bureau were identified and data on them furnished for their owners.

Personnel.—Dr. Truman Michelson, ethnologist, died July 26, 1938. On February 1, 1939, Henry B. Collins, Jr., was appointed by transfer from the United States National Museum to fill the vacancy caused by the death of Dr. Michelson. Dr. William N. Fenton was appointed as ethnologist on February 6, 1939. H. B. Chappell resigned as clerk in the library of the Bureau on October 4, 1938, and Walter B. Greenwood was appointed on November 1, 1938, to fill this vacancy. Stanley Searles, editor, retired on June 30, 1939.

Respectfully submitted.

M. W. Stirling, *Chief.*

Dr. C. G. Abbot,
Secretary, Smithsonian Institution.

APPENDIX 6

REPORT ON THE INTERNATIONAL EXCHANGE SERVICE

SIR: I have the honor to submit the following report on the activities of the International Exchange Service during the fiscal year ended June 30, 1939:

The appropriation granted by Congress for that year was $44,600, an increase over 1938 of $340. The collections from repayments were $3,684.03, making the total available resources $48,284.03.

The number of packages passing through the service was 714,877, a decrease of 4,244. The weight was 719,694 pounds, an increase of 63,575 pounds.

The number and weight of packages sent and received through the service is given below:

	Packages		Weight	
	Sent	Received	Sent	Received
			Pounds	*Pounds*
United States parliamentary documents sent abroad	311,120		121,463	
Publications received in return for parliamentary documents		10,132		32,796
United States departmental documents sent abroad	137,303		138,606	
Publications received in return for departmental documents		11,185		35,761
Miscellaneous scientific and literary publications sent abroad	192,129		273,128	
Miscellaneous scientific and literary publications received from abroad for distribution in the United States		53,008		117,940
Total	640,552	74,325	533,197	186,497
Grand total	714,877		719,694	

There were shipped abroad 3,023 boxes, an increase of 384 over the preceding year. Of these boxes, 623 were for depositories of full sets of United States governmental documents, and the remainder were for distribution to miscellaneous establishments and individuals.

In some instances it is more advantageous or economical to send packages by mail, paying the postage, than to forward them in boxes by freight to exchange agencies for distribution. During the year there were transmitted in this manner 90,355 packages, a decrease from the last 12 months of 21,120. In addition to transmitting by mail packages on which it is necessary to pay postage, a large

number are sent directly to their destinations under Government frank, the franking privilege between the United States and certain foreign countries having been arranged by the United States postal authorities and those of the respective countries. A list of the countries with which this privilege is in effect is as follows: Canada, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, Guatemala, Haiti, Honduras, Mexico, Newfoundland (including Labrador), Nicaragua, Panama, Paraguay, Peru, Salvador, Uruguay, and Venezuela.

Shipments to Spain are still suspended. However, efforts are being made through diplomatic channels to resume exchange relations with that country.

Last year mention was made that packages for the National Library of Peiping, the Engineering Reference Library, Nanking, and the Library Association of China were being forwarded to the temporary address of those organizations in Hong Kong, in accordance with the request of Dr. T. L. Yuan who is officially connected therewith. Up to June 30 there were transmitted to those libraries 251 boxes weighing 54,800 pounds and containing more than 36,000 packages of publications presented by individuals and establishments throughout the United States. In acknowledging several large consignments, Dr. Yuan writes as follows:

> May I take this opportunity of expressing to you once more our sincere appreciation and grateful thanks for the most efficient manner in which you have assisted China in the great task of rebuilding our intellectual edifice.
>
> Arm in arm with resistance, the Chinese people are carrying out an extensive program of reconstruction, particularly in the Southwest. We have taken special steps to see that the publications are placed in centers where they will be used to the best advantage. You may be sure of the special care and thought which Chinese libraries will give in preserving them and in making them available to the largest number of interested readers.

Just before the close of the year Lingnan University Library, Canton, informed the Institution that it had moved to Hong Kong and requested that publications for that library be sent in care of the Fung Ping Shan Library, Bonham Road, Hong Kong.

Packages for all addresses in China other than those referred to above are forwarded to the Chinese Bureau of International Exchange in Chungking.

The chart (fig. 1) shows the relative weight of packages transmitted through the International Exchange Service between the years 1850, when the service was inaugurated, and 1939, divided into periods of 5 years. The decrease in the weight for the 1915 to 1919 period was due to the disturbance of international relations incident to the World War.

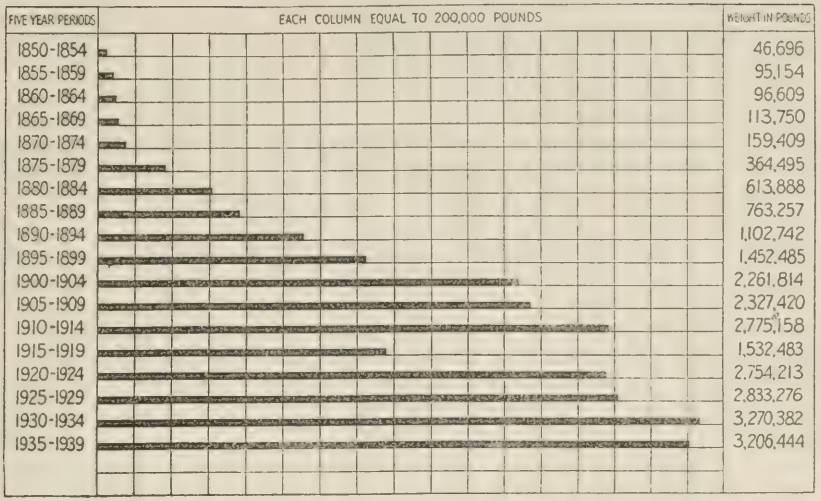


FIGURE 1.—Relative weight of packages transmitted through the International Exchange Service between the years 1850 and 1939, divided into periods of 5 years each.

FOREIGN DEPOSITORIES OF GOVERNMENTAL DOCUMENTS

There are now transmitted through the service to foreign depositories 61 full sets of United States official documents and 47 partial sets—108 in all, a decrease of 3 sets. The partial sets for the city of Glasgow, Assam, and Central Provinces were discontinued, and the partial set for Finland was increased to a full set.

At the request of the Danish Government the depository in that country was changed from the Royal Library to the Royal Danish Academy of Sciences in Copenhagen.

The German Government depository was changed from the Ministry of the Interior to the Ministry of Science, Instruction, and Public Education.

DEPOSITORIES OF FULL SETS

ARGENTINA: Ministerio de Relaciones Exteriores, Buenos Aires.
BUENOS AIRES: Biblioteca de la Universidad Nacional de La Plata, La Plata. (Depository of the Province of Buenos Aires.)
AUSTRALIA: Commonwealth Parliament and National Library, Canberra.
NEW SOUTH WALES: Public Library of New South Wales, Sydney.
QUEENSLAND: Parliamentary Library, Brisbane.
SOUTH AUSTRALIA: Parliamentary Library, Adelaide.
TASMANIA: Parliamentary Library, Hobart.
VICTORIA: Public Library of Victoria, Melbourne.
WESTERN AUSTRALIA: Public Library of Western Australia, Perth.
BELGIUM: Bibliothèque Royale, Bruxelles.
BRAZIL: Bibliotheca Nacional, Rio de Janeiro.

CANADA: Library of Parliament, Ottawa.
MANITOBA: Provincial Library, Winnipeg.
ONTARIO: Legislative Library, Toronto.
QUEBEC: Library of the Legislature of the Province of Quebec.
CHILE: Biblioteca Nacional, Santiago.
CHINA: Bureau of International Exchange, Ministry of Education, Chungking.
COLOMBIA: Biblioteca Nacional, Bogotá.
COSTA RICA: Oficina de Depósito y Canje Internacional de Publicaciones, San José.
CUBA: Secretaría de Estado, Dirección de Relaciones Culturales, Habana.
CZECHOSLOVAKIA: Bibliothèque de l'Assemblée Nationale, Prague. Shipments temporarily suspended.
DENMARK: Kongelige Danske Videnskabernes Selskab, Copenhagen.
EGYPT: Bureau des Publications, Ministère des Finances, Cairo.
ESTONIA: Riigiraamatukogu (State Library), Tallinn.
FINLAND: Parliamentary Library, Helsingfors.
FRANCE: Bibliothèque Nationale, Paris.
GERMANY: Reichstauschstelle im Reichsministerium für Wissenschaft, Erziehung und Volksbildung, Berlin, N. W. 7.
AUSTRIA: National-Bibliothek, Wien, I.
BADEN: Universitäts-Bibliothek, Freiburg. (Depository of the State of Baden.)
BAVARIA: Bayerische Staatsbibliothek, München.
PRUSSIA: Preussische Staatsbibliothek, Berlin, N. W. 7.
SAXONY: Sächsische Landesbibliothek, Dresden—N. 6.
WURTEMBURG: Landesbibliothek, Stuttgart.
GREAT BRITAIN:
ENGLAND: British Museum, London.
LONDON: London School of Economics and Political Science. (Depository of the London County Council.)
HUNGARY: Library, Hungarian House of Delegates, Budapest.
INDIA: Imperial Library, Calcutta.
IRELAND: National Library of Ireland, Dublin.
ITALY: Ministero dell'Educazione Nazionale, Rome.
JAPAN: Imperial Library of Japan, Tokyo.
LATVIA: Bibliothèque d'État, Riga.
LEAGUE OF NATIONS: Library of the League of Nations, Geneva, Switzerland.
MEXICO: Departamento Autónomo de Prensa y Publicidad, Mexico, D. F.
NETHERLANDS: Royal Library, The Hague.
NEW ZEALAND: General Assembly Library, Wellington.
NORTHERN IRELAND: H. M. Stationery Office, Belfast.
NORWAY: Universitets-Bibliothek, Oslo. (Depository of the Government of Norway.)
PERU: Sección de Propaganda y Publicaciones, Ministerio de Relaciones Exteriores, Lima.
POLAND: Bibliothèque Nationale, Warsaw.
PORTUGAL: Bibliotheca Nacional, Lisbon.
RUMANIA: Academia Română, Bucharest.
SPAIN: Servicio de Cambio Internacional de Publicaciones, Paseo de Recoletos 20, Madrid. Shipments suspended since August 1936.
SWEDEN: Kungliga Biblioteket, Stockholm.
SWITZERLAND: Bibliothèque Centrale Fédérale, Berne.
TURKEY: Department of Printing and Engraving, Ministry of Education, Istanbul.

UNION OF SOUTH AFRICA: State Library, Pretoria, Transvaal.
UNION OF SOVIET SOCIALIST REPUBLICS: All-Union Lenin Library, Moscow 115.
UKRAINE: All-Ukrainian Association for Cultural Relations with Foreign Countries, Kiev.
URUGUAY: Oficina de Canje Internacional de Publicaciones, Montevideo.
VENEZUELA: Biblioteca Nacional, Caracas.
YUGOSLAVIA: Ministère de l'Education, Belgrade.

DEPOSITORIES OF PARTIAL SETS

AFGHANISTAN: Ministry of Foreign Affairs, Publications Department, Kabul.
BOLIVIA: Biblioteca del H. Congreso Nacional, La Paz.
BRAZIL:
MINAS GERAES: Directoria Geral de Estatistica em Minas, Bello Horizonte.
RIO DE JANEIRO: Bibliotheca da Assemblea Legislativa do Estado, Nictheroy.
BRITISH GUIANA: Government Secretary's Office, Georgetown, Demerara.
BULGARIA: Ministère des Affaires Étrangères, Sofia.
CANADA:
ALBERTA: Provincial Library, Edmonton.
BRITISH COLUMBIA: Provincial Library, Victoria.
NEW BRUNSWICK: Legislative Library, Fredericton.
NOVA SCOTIA: Provincial Secretary of Nova Scotia, Halifax.
PRINCE EDWARD ISLAND: Legislative Library, Charlottetown.
SASKATCHEWAN: Legislative Library, Regina.
CEYLON: Chief Secretary's Office (Record Department of the Library), Colombo.
CHINA: National Library of Peiping, % Fung Ping Shan Chinese Library, Hong Kong.
DANZIG: Stadtbibliotheek, Danzig.
DOMINICAN REPUBLIC: Biblioteca del Senado, Ciudad Trujillo.
ECUADOR: Biblioteca Nacional, Quito.
GERMANY:
BREMEN: Staatsbibliothek.
HAMBURG: Staats-und Universitäts-Bibliotheek.
HESSE: Universitäts-Bibliothek, Giessen.
LÜBECK: President of the Senate.
THURINGIA: Rothenberg-Bibliothek, Landesuniversität, Jena.
VIENNA: Magistrat der Stadt Wien, Abteilung 47 Statistik, Wien IV.
GREECE: Library of Parliament, Athens.
GUATEMALA: Biblioteca Nacional, Guatemala.
HAITI: Secrétaire d'État des Relations Extérieures, Port-au-Prince.
HONDURAS: Biblioteca y Archivo Nacionales, Tegucigalpa.
ICELAND: National Library, Reykjavik.
INDIA:
BENGAL: Secretary, Bengal Legislative Council Department, Council House, Calcutta.
BIHAR AND ORISSA: Revenue Department, Patna.
BOMBAY: Undersecretary to the Government of Bombay, General Department, Bombay.
BURMA: Secretary to the Government of Burma, Education Department, Rangoon.
MADRAS: Chief Secretary to the Government of Madras, Public Department, Madras.
PUNJAB: Chief Secretary to the Government of the Punjab, Lahore.
UNITED PROVINCES OF AGRA AND OUDH: University of Allahabad, Allahabad.

JAMAICA: Colonial Secretary, Kingston.
LIBERIA: Department of State, Monrovia.
LITHUANIA: Ministère des Affaires Étrangères, Kaunas (Kovno).
MALTA: Minister for the Treasury, Valletta.
NEWFOUNDLAND: Department of Home Affairs, St. John's.
NICARAGUA: Superintendente de Archivos Nacionales, Managua.
PANAMA: Secretaría de Relaciones Exteriores, Panama.
PARAGUAY: Secretario de la Presidencia de la República, Asunción.
SALVADOR: Ministerio de Relaciones Exteriores, San Salvador.
STRAITS SETTLEMENTS: Colonial Secretary, Singapore.
THAILAND: Department of Foreign Affairs, Bangkok.
VATICAN CITY: Biblioteca Apostolica Vaticana, Vatican City, Italy.

INTERPARLIAMENTARY EXCHANGE OF THE OFFICIAL JOURNAL

The number of copies of the Congressional Record and the Federal Register sent to foreign depositories has been reduced to 103. The Records sent to Bolivia and the Dominican Republic were discontinued, and there was added to the list the Bibliotheek van de Tweede Kamer der Staten-General, The Hague, Netherlands.

DEPOSITORIES OF CONGRESSIONAL RECORD

ALBANIA: Ministrija Mbretnore e Punëvetë Jashtme, Tirana.
ARGENTINA:
Biblioteca del Congreso Nacional, Buenos Aires.
Cámara de Diputados, Oficina de Información Parlamentaria, Buenos Aires.
Boletín Oficial de la República Argentina, Ministerio de Justicia e Instrucción Pública, Buenos Aires.
AUSTRALIA:
Library of the Commonwealth Parliament, Canberra.
NEW SOUTH WALES: Library of Parliament of New South Wales, Sydney.
QUEENSLAND: Chief Secretary's Office, Brisbane.
WESTERN AUSTRALIA: Library of Parliament of Western Australia, Perth.
BELGIUM: Bibliothèque de la Chambre des Représentants, Bruxelles.
BRAZIL:
Bibliotheca do Congresso Nacional, Rio de Janeiro.
AMAZONAS: Archivo, Bibliotheca e Imprensa Publica, Manáos.
BAHIA: Governador do Estado da Bahia, São Salvador.
ESPIRITO SANTO: Presidencia do Estado do Espirito Santo, Victoria.
RIO GRANDE DO SUL: "A Federação," Porto Alegre.
SERGIPE: Bibliotheca Publica do Estado de Sergipe, Aracajú.
SÃO PAULO: Diario Official do Estado de São Paulo, São Paulo.
BRITISH HONDURAS: Colonial Secretary, Belize.
CANADA:
Library of Parliament, Ottawa.
Clerk of the Senate, Houses of Parliament, Ottawa.
CHINA: National Central Library, Nanking.
CUBA: Biblioteca del Capitolio, Habana.
CZECHOSLOVAKIA: Bibliothèque de l'Assemblée Nationale, Prague.
DENMARK: Rigsdagens Bureau, Copenhagen.
EGYPT:
Chambre des Députés, Cairo. Sénat, Cairo.

FRANCE:
Chambre des Députés, Service de l'Information Parlementaire Étrangère, Paris.
Bibliothèque du Sénat, au Palais du Luxembourg, Paris.
Bureau de Documentation Générale, Ministère des Finances, Paris I.
Bibliothèque, Direction des Accords commerciaux, Ministère du Commerce, Paris.
GERMANY:
Deutsche Reichstags-Bibliothek, Berlin, N. W. 7.
Reichsfinanzministerium, Berlin, W. 8.
ANHALT: Anhaltische Landesbücherei, Dessau.
AUSTRIA: Bibliothek im Parlament, Wien I.
BRAUNSCHWEIG: Bibliothek des Braunschweigischen Staatministeriums, Braunschweig.
MECKLENBURG: Staatsministerium, Schwerin.
OLDENBURG: Oldenburgisches Staatsministerium, Oldenburg i. O.
SCHAUMBURG-LIPPE: Schaumburg-Lippische Landesregierung, Bückeburg.
GIBRALTAR: Gibraltar Garrison Library Committee, Gibraltar.
GREAT BRITAIN: Library of the Foreign Office, London.
GREECE: Library of Parliament, Athens.
GUATEMALA: Biblioteca de la Asamblea Legislativa, Guatemala.
HONDURAS: Biblioteca del Congreso Nacional, Tegucigalpa.
HUNGARY: A Magyar országgyülés könyvtará, Budapest.
INDIA: Legislative Department, Simla.
INDOCHINA: Gouverneur Général de l'Indochine, Hanoi.
IRAN: Library of the Iranian Parliament, Téhéran.
IRAQ: Chamber of Deputies, Baghdad.
IRISH FREE STATE: Dail Eireann, Dublin.
ITALY:
Biblioteca della Camera dei Deputati, Rome.
Biblioteca del Senato del Regno, Rome.
Ufficio degli Studi Legislativi, Senato del Regno, Rome.
LATVIA: Valsts Biblioteka, Riga.
LEAGUE OF NATIONS: Library of the League of Nations, Geneva, Switzerland.
LEBANON: Ministère des Finances de la République Libanaise, Service du Matériel, Beirut.
LIBERIA: Department of State, Monrovia.
MEXICO: Departamento Autónomo de Prensa y Publicidad, Mexico, D. F.
AGUASCALIENTES: Gobernador del Estado de Aguascalientes, Aguascalientes.
CAMPECHE: Gobernador del Estado de Campeche, Campeche.
CHIAPAS: Gobernador del Estado de Chiapas, Tuxtla Gutierrez.
CHIHUAHUA: Gobernador del Estado de Chihuahua, Chihuahua.
COAHUILA: Periódico Oficial del Estado de Coahuila, Palacio de Gobierno, Saltillo.
COLIMA: Gobernador del Estado de Colima, Colima.
DURANGO: Gobernador Constitucional del Estado de Durango, Durango.
GUANAJUATO: Secretaría General de Gobierno del Estado, Guanajuato.
GUERRERO: Gobernador del Estado de Guerrero, Chilpancingo.
JALISCO: Biblioteca del Estado, Guadalajara.
LOWER CALIFORNIA: Gobernador del Distrito Norte, Mexicali, B. C., Mexico.
MEXICO: Gaceta del Gobierno, Toluca, Mexico.
MICHOACÁN: Secretaría General de Gobierno del Estado de Michoacán, Morelia.

MEXICO: Departmento Autónomo de Prensa y Publicidad, Mexico, D. F.—Contd.
MORELOS: Palacio de Gobierno, Cuernavaca.
NAYARIT: Gobernador de Nayarit, Tepic.
NUEVO LEON: Biblioteca del Estado, Monterey.
OAXACA: Periódico Oficial, Palacio de Gobierno, Oaxaca.
PUEBLA: Secretaría General de Gobierno, Puebla.
QUERETARO: Secretaría General de Gobierno, Sección de Archivo, Queretaro.
SAN LUIS POTOSI: Congreso del Estado, San Luis Potosi.
SINALOA: Gobernador del Estado de Sinaloa, Culiacan.
SONORA: Gobernador del Estado de Sonora, Hermosillo.
TABASCO: Secretaría General de Gobierno, Sección 3a, Ramo de Prensa, Villahermosa.
TAMAULIPAS: Secretaría General de Gobierno, Victoria.
TLAXCALA: Secretaría de Gobierno del Estado, Tlaxcala.
VERA CRUZ: Gobernador del Estado de Vera Cruz, Departamento de Gobernación y Justicia, Jalapa.
YUCATÁN: Gobernador del Estado de Yucatán, Mérida, Yucatán.
NETHERLANDS: Bibliotheek van de Tweede Kamer der Staten-General, The Hague.
NETHERLANDS INDIES: Volksraad von Nederlandsch-Indië, Batavia, Java.
NEW ZEALAND: General Assembly Library, Wellington.
NORWAY: Storthingets Bibliothek, Oslo.
PERU: Cámara de Diputados, Lima.
POLAND: Bibljoteka Narodowa, Warsaw.
PORTUGAL: Secretario da Assemblea Nacional, Lisboa.
RUMANIA:
Bibliothèque de la Chambre des Députés, Bucharest.
Ministère des Affaires Étrangères, Bucharest.
SPAIN:
Biblioteca del Congreso Nacional, Madrid.
CATALUNYA: Biblioteca del Parlament de Catalunya, Barcelona. Suspended.
SWITZERLAND: Bibliothèque de l'Assemblée Fédérale Suisse, Berne.
BERN: Staatskanzlei des Kantons Bern.
ST. GALLEN: Staatskanzlei des Kantons St. Gallen.
SCHAFFHAUSEN: Staatskanzlei des Kantons Schaffhausen.
ZÜRICH: Staatskanzlei des Kantons Zürich.
TURKEY: Turkish Grand National Assembly, Ankara.
UNION OF SOUTH AFRICA:
Library of Parliament, Cape Town, Cape of Good Hope.
State Library, Pretoria, Transvaal.
URUGUAY: Diario Oficial, Calle Florida 1178, Montevideo.
VENEZUELA: Biblioteca del Congreso, Caracas.
VATICAN CITY: Biblioteca Apostolica Vaticana, Vatican City, Italy.

FOREIGN EXCHANGE AGENCIES

For several years the Robert College at Istanbul has been good enough to act as the exchange agency for Turkey and has promptly forwarded to their destinations all packages transmitted in its care. For this service the Institution is indebted to Robert College. The work is now being taken over by the Department of Printing and Engraving, Ministry of Education, Istanbul.

A list of the foreign exchange bureaus is given below. Most of those bureaus forward consignments of publications to the Institution for distribution in the United States.

LIST OF AGENCIES

ALGERIA, via France.
ANGOLA, via Portugal.
ARGENTINA: Comisión Protectora de Bibliotecas Populares, Canje Internacional, Calle Callao 1540, Buenos Aires.
AUSTRIA: Internationale Austauschstelle, National-Bibliothek, Wien I.
AZORES, via Portugal.
BELGIUM: Service Belge des Échanges Internationaux, Bibliothèque Royale de Belgique, Bruxelles.
BOLIVIA: Sent by mail.
BRAZIL: Serviço de Permutações Internacionaes, Bibliotheca Nacional, Rio de Janeiro.
BRITISH GUIANA: Sent by mail.
BRITISH HONDURAS: Sent by mail.
BULGARIA: Sent by mail.
CANADA: Sent by mail.
CANARY ISLANDS, via Spain.
CHILE: Sent by mail.
CHINA: Bureau of International Exchange, Ministry of Education, Chungking.
COLOMBIA: Sent by mail.
COSTA RICA: Sent by mail.
CUBA: Sent by mail.
CZECHOSLOVAKIA: Service des Échanges Internationaux, Bibliothèque de l'Assemblée Nationale, Prague 1–79.
DANZIG: Sent by mail.
DENMARK: Service Danois des Échanges Internationaux, Kongelige Danske Videnskabernes Selskab, Copenhagen V.
DOMINICAN REPUBLIC: Sent by mail.
ECUADOR: Sent by mail.
EGYPT: Government Press, Publications Office, Bulaq, Cairo.
ESTONIA: Riigiraamatukogu (State Library), Tallinn.
FINLAND: Delegation of the Scientific Societies of Finland, Kasärngatan 24, Helsingfors.
FRANCE: Service Français des Échanges Internationaux, 110 Rue de Grenelle, Paris.
FRENCH GUIANA: Sent by mail.
GERMANY: Amerika-Institut, Universitätstrasse 8, Berlin, N. W. 7.
GREAT BRITAIN AND IRELAND: Wheldon & Wesley, 2–4 Earnshaw St., New Oxford St., London, W. C. 2.
GREECE: Sent by mail.
GREENLAND, via Denmark.
GUATEMALA: Sent by mail.
HAITI: Sent by mail.
HONDURAS: Sent by mail.
HUNGARY: Hungarian Libraries Board, Ferenciektere 5, Budapest, IV.
ICELAND, via Denmark.
INDIA: Superintendent of Government Printing and Stationery, Bombay.
ITALY: Ufficio degli Scambi Internazionali, Ministero dell'Educazione Nazionale, Rome.

JAMAICA: Sent by mail.
JAPAN: International Exchange Service, Imperial Library of Japan, Uyeno Park, Tokyo.
JAVA, via Netherlands.
LATAKIA: Sent by mail.
LATVIA: Service des Échanges Internationaux, Bibliothèque d'Etat de Lettonie, Riga.
LEBANON: Sent by mail.
LIBERIA: Sent by mail.
LITHUANIA: Sent by mail.
LUXEMBOURG, via Belgium.
MADAGASCAR, via France.
MADEIRA, via Portugal.
MEXICO: Sent by mail.
MOZAMBIQUE, via Portugal.
NETHERLANDS: International Exchange Bureau of the Netherlands, Royal Library, The Hague.
NEWFOUNDLAND AND LABRADOR: Sent by mail.
NEW SOUTH WALES: Public Library of New South Wales, Sydney.
NEW ZEALAND: General Assembly Library, Wellington.
NICARAGUA: Sent by mail.
NORWAY: Service Norvégien des Échanges Internationaux, Bibliothèque de l'Université Royale, Oslo.
PALESTINE: Jewish National and University Library, Jerusalem.
PANAMA: Sent by mail.
PARAGUAY: Sent by mail.
PERU: Sent by mail.
POLAND: Service Polonais des Échanges Internationaux, Bibliothèque Nationale, Warsaw.
PORTUGAL: Secção de Trocas Internacionaes, Bibliotheca Nacional, Lisboa.
QUEENSLAND: Bureau of Exchanges of International Publications, Chief Secretary's Office, Brisbane.
RUMANIA: Soussecrétariat d'Etat de la Propagande, Direction de la Presse, Service des Échanges Internationaux, Bucharest.
SALVADOR: Sent by mail.
SOUTH AUSTRALIA: South Australian Government Exchanges Bureau, Government Printing and Stationery Office, Adelaide.
SPAIN: Shipments suspended since August 1936.
SUMATRA, via Netherlands.
SURINAM: Sent by mail.
SWEDEN: Kongliga Svenska Vetenskaps Akademien, Stockholm.
SWITZERLAND: Service Suisse des Echanges Internationaux, Bibliothèque Centrale Fédérale, Berne.
SYRIA: Sent by mail.
TASMANIA: Secretary to the Premier, Hobart.
THAILAND: Sent by mail.
TRINIDAD: Sent by mail.
TUNIS, via France.
TURKEY: Ministry of Education, Department of Printing and Engraving, Istanbul.
UNION OF SOUTH AFRICA: Government Printing and Stationery Office, Capetown, Cape of Good Hope.

UNION OF SOVIET SOCIALIST REPUBLICS: Library of the Academy of Sciences of the U. S. S. R., Exchange Service, Leningrad, V. O.
URUGUAY: Sent by mail.
VENEZUELA: Sent by mail.
VICTORIA: Public Library of Victoria, Melbourne.
WESTERN AUSTRALIA: Public Library of Western Australia, Perth.
YUGOSLAVIA: Section des Echanges Internationaux, Ministère des Affaires Étrangères, Belgrade.

Respectfully submitted.

F. E. GASS,
Acting Chief Clerk.

Dr. C. G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 7

REPORT ON THE NATIONAL ZOOLOGICAL PARK

SIR: I have the honor to submit the following report on the operations of the National Zoological Park for the fiscal year ended June 30, 1939:

The regular appropriation made by Congress for the maintenance of the Park was $227,000, all of which was expended.

IMPROVEMENTS

Extensive and important improvements of a varied nature were completed during the year. These were accomplished through close cooperation with W. P. A. labor under excellent supervision. This labor was available the entire year.

The grading between the large mammal house and the refreshment stand, begun in the last fiscal year, was completed. This includes a stone retaining wall around the base of the hill. A stone feed house 100 feet long and 30 feet wide was constructed. It is a one-story building with cellar arranged for storing vegetables and with ample storage space for hay and grains.

One of the largest of the jobs of the year was the grading and excavating of approximately 80,000 cubic yards of earth at what had been known as the buffalo hill. On this site one large buffalo paddock has been completed. This is an enclosure 170 by 140 to 150 feet, with a shelter 81 by 20 feet. On this site are also being constructed four paddocks, of nearly equal size, covering an area 350 by 150 feet. These four paddocks are of the barless type with dry moats separating visitors from the animals. For shelter on these paddocks two buildings, one 20 by 40 feet, and the other 20 by 48 feet, have been constructed. This entire unit is about 95 percent completed. A paddock 50 feet long and 30 feet wide has been added to the wild horse and zebra group.

A group of circular enclosures, making an exceptionally fine exhibition place for raccoons, prairie dogs, and cavies, have been constructed between the small mammal house and the antelope building. These are about 50 feet in diameter with concrete side walls of two of them about 3 feet deep and the other, for prairie dogs, with side walls in the ground about 10 feet and provision for bottom drainage.

A reinforced concrete pool of irregular design, with a small waterfall was completed back of the bird house. This is about 53 by 23

feet, with open moat effect and enclosed by a paneled guard rail.

A 3-inch water main was laid from the cockatoo cage to the rear of the bird house, a total of 625 linear feet.

New concrete walks were completed back of the bird house and around the large mammal house covering a total area of 1,200 square yards. A total of 7,880 square yards of bituminous concrete was laid. This included roads, walks, and a splendid parking area for buses on the main road below the large mammal house. About 3,400 linear feet of reinforced concrete curbing was constructed. An important improvement from the standpoint of safety was the construction of an underground duct for the high tension, three-phase electric supply line from the point at which it enters the Park, to the bird house. This covered a total distance of about 715 linear feet.

A total of 4,900 square yards of road were repaired and resurfaced with bipac. In connection with the excavating and fills, and new road and walk work, about 1,600 feet of surface and gutter drains were laid. The old smokestack, in use prior to the development of the new shops in 1936, was demolished.

A definite aid to the always-present parking problem was the improvement of several parking areas.

With the completion of the principal buildings and grading adjacent to the structures and landscape grading elsewhere about the Park, there were considerable barren areas that required planting. Accordingly, during the fiscal year extensive plantings were made of holly, flowering crab, flowering peach, dogwood, native forest trees, such as beech, walnut, ash, elm, hickory, Virginia cedar, Virginia pine, red pine, red spruce, hemlocks, and ornamental shrubs such as hibiscus, abelia, forsythia, spirea, japonica, azaleas, and privet. In all, more than 400 trees and 600 shrubs were planted and about 5 acres were seeded to grass.

The Zoo is indebted to Dr. Francis B. Lincoln, of the Maryland Agricultural Experiment Station, for hollys, flowering crabs, flowering peaches, evergreens, roses, jasmine, sand cherries, ilex, and other shrubs; to the United States Forest Service for pines and spruces; to the United States Soldiers' Home for evergreens, japonica, amelanchier, crepe myrtle, magnolias, and figs; to Clifford Lanham, of the District Nursery, for Chinese elm and maples; to Dr. Ira N. Gabrielson, Chief of the United States Biological Survey, for sweet gum and pines. Mrs. Mary G. Corby very kindly permitted us to obtain cedars, wisterias, barberries, and pines from her estate.

These improvements were carried on with the minimum of cost. All stone used was quarried in the Park. Sand and gravel were also obtained from the creek bed in the Park.

RESTAURANT

The Public Works Administration allotted the sum of $90,000 for the much-needed restaurant building at the Park.

Work on plans for this building was commenced immediately by the Supervising Architect, Procurement Division, Treasury Department, and in a short time it is expected that bids will be let and construction begun.

This will be a marked improvement in the service that the Zoo gives to the public.

FIELD WORK

The appropriation bill for the Zoo carried an item of $2,000 for travel. With part of this money Malcolm Davis of the Zoo staff was sent to Calcutta to bring back an Indian rhinoceros that had been captured by the Forestry Service of Assam through the interest of United States Consul General White. At the present time Mr. Davis is at sea with the rhino and a shipment of other animals collected by him.

With the remainder of the money a short trip was made by the Director to the Argentine. A small collection of animals was taken for exchange with the zoos in Buenos Aires, La Plata, and Cordoba. United States Consul General Monnett B. Davis took an active interest in the expedition, and Dr. A. Holmberg, Director of the Buenos Aires Zoo, planned the field work. The Minister of Agriculture sent the party in his yacht down the Delta of the Parana. The Governor of Cordoba furnished transportation into the hills, and the National Park Service supplied transportation to the famous Nahuel Huapi National Park. On all of these side trips specimens were obtained. The zoos presented many specimens, as did Natalio Botana, José M. Cinaghi, and Ennio Arrigutti of the Aquarium Kin-Yu. Tom Davis, of Buenos Aires, made a large collection of Argentine tortoises and terrapins which he presented to the expedition. On the return voyage a number of specimens were obtained from the zoo at Rio Janeiro, and some snakes from the Instituto Butantan at Sao Paolo. In all, 70 crates of live animals were landed at Washington. There are many difficulties connected with traveling with animals, but the officials and the officers and crew of the Moore-McCormack Lines, Inc., cooperated in every way possible, and thanks are due to them for making the expedition such a success.

A summary of the specimens brought back follows:

Class	Species	Individuals
Mammals	12	35
Birds	26	177
Reptiles	17	98
Amphibians	3	6
Total	58	316

NEEDS OF THE ZOO

The Zoo now has four fine exhibition buildings, but there are three old ones, housing lions, monkeys, and antelopes, that are most unsatisfactory and unsuitable buildings. It is hoped that appropriations can be made to replace these structures with modern buildings which would complete the development of the Zoo as far as large animal houses are concerned.

VISITORS FOR THE YEAR

There was a decrease in the attendance for the year compared with last year. The return in the fall of 1937 of the National Geographic-Smithsonian Institution East Indies Expedition brought out large crowds which continued visiting the Park far into the winter, when attendance is usually small.

July	251,000	February	118,530
August	239,500	March	151,700
September	263,400	April	291,600
October	158,100	May	232,100
November	134,400	June	193,600
December	80,200		
January	86,950	Total	2,201,080

The attendance of organizations, mainly classes of students, of which there is definite record, was 37,220, from 699 different schools in 22 States and the District of Columbia as follows:

State	Number of persons	Number of parties	State	Number of persons	Number of parties
Alabama	30	1	New Jersey	2,806	32
Connecticut	449	9	New York	1,965	25
Delaware	242	6	North Carolina	783	24
District of Columbia	8,662	152	Ohio	596	17
Florida	66	2	Oklahoma	80	1
Georgia	377	9	Pennsylvania	6,562	134
Illinois	37	1	South Carolina	541	16
Indiana	20	1	Tennessee	137	4
Kentucky	50	1	Virginia	6,077	131
Maine	42	1	West Virginia	742	19
Maryland	6,404	102	Miscellaneous	137	2
Massachusetts	276	6			
Michigan	139	3	Total	37,220	699

About 3 o'clock every afternoon, except Sundays and holidays, a census is taken of the cars parked on the Zoo grounds. During the year, 27,932 were so listed, representing every State in the Union, Canada, Canal Zone, Cuba, Panama, Hawaii, Bahamas, Puerto Rico, Guam, and the Philippine Islands.

Since the total number is merely a record of those actually parked at one time, it is not of value as indicating a total attendance but

is of importance as showing the percentage attendance by States, territories, and countries. The District of Columbia comprised slightly over 46 percent; Maryland, 19 percent; Virginia, 11 percent; and the remaining cars were from other States, Territories, and countries. During years in which counts have been made on Sunday as well as during the week it has been found that the percentage of cars from the District of Columbia, Maryland, and Virginia is less, and the percentage of more distant States is correspondingly increased. This is brought about by tourists coming to the Zoo on Sundays when other points of interest are closed to them.

ACCESSIONS

Gifts.—A number of specimens were received as gifts during the year. These were gratefully received and acknowledgement is made in a complete list of donors and their gifts. Among the most interesting additions were 10 Louisiana herons and 11 snowy egrets from A. E. McIlhenny, Avery Island, La. Dr. Waldo L. Schmitt, of the United States National Museum presented 76 land hermit crabs; also, as a result of the Presidential cruise to southern waters in the summer of 1938, in which he participated, he presented the Park with a Galápagos hawk, 2 species of snakes never before exhibited at the Park, one from James Island and one from Hood Island. From the same cruise, through Lt. L. H. Le Hardy, the Park received a Galápagos iguana. A fine collection of Central American reptiles was received from Costello Craig, Washington, D. C.

The United States Biological Survey, through Roy Fugit and Joseph L. Crummett, Pendleton, Oreg., presented 6 Nevada long-eared foxes.

DONORS AND THEIR GIFTS

H. A. Allard, Washington, D. C., gopher turtle.
O. R. Anderson, Washington, D. C., 2 skunks.
J. P. Andrews, Farmville, Va., bald eagle.
Tom C. Atkinson, Toledo, Ohio, 2 massasaugas.
Dr. L. Avery, Beltsville, Md., opossum.
Mrs. Pedro Ayson, Washington, D. C., Cuban parrot.
Mrs. J. H. Baden, Washington, D. C., barred owl.
A. G. Baker, Youngstown, Ohio, 6 massasaugas.
L. R. Baker, Washington, D. C., ovenbird.
Edgar Bayly, Washington, D. C., 2 alligators.
Charles Bell, Washington, D. C., Florida gallinule.
Mrs. Boccabella, Washington, D. C., 2 grass paroquets.
Mrs. Bon, Washington, D. C., alligator.
Jack Brown, Washington, D. C., 2 rice birds.
Ralph D. Brown, Washington, D. C., 4 European goldfinches.

Frank H. Burch, Silver Spring, Md., raccoon.
A. L. Burnett, Clarendon, Va., raccoon.
D. E. Butler, Washington, D. C., Philippine monkey.
Walter J. Butler, Washington, D. C., towhee.
Mrs. E. Buzzone, Washington, D. C., yellow-naped parrot.
N. W. Canter, Washington, D. C., large brown bat.
O. W. Chesley, Fairfax, Va., broad-winged hawk.
Donald Collier, Alexandria, Va., opossum.
Mrs. Connole, Arlington, Va., crow.
Walter Coombs, Washington, D. C., albino grass snake.
James Coon, Washington, D. C., red-tailed hawk.
R. B. Covington, Washington, D. C., 2 mallards.
Costello Craig, Washington, D. C., 3 Central American musk turtles, 2 ornate turtles, 4 caimans, 3 coatimundis, fer-de-lance, 15 emperor boas, 2 indigo snakes, pike-headed tree snake, vine snake, 3 night snakes, parrot snake, 2 tarantulas.
Lindsay Crawford, Washington, D. C., troupial.
J. E. Darrer, Washington, D. C., barred owl.
Malcolm Davis, Washington, D. C., 13 marine toads.
Walter B. Davis, Washington, D. C., 2 grass paroquets.
Freddie Deininger, Washington, D. C., opossum, rabbit.
L. L. Derrick, Washington, D. C., 2 fox squirrels.
Congressman John D. Dingell, Washington, D. C., opossum.
Mrs. L. T. Ditoran, Berwyn, Md., chain or king snake.
Mrs. H. W. Elmore, Washington, D. C., raccoon.
Mrs. K. C. Ewing, Pikesville, Md., 2 coatimundis, 2 brown capuchins.
Wesley Feagin, Long Beach, Calif., 2 sidewinder rattlesnakes, 2 Pacific gopher snakes, 3 desert leaf-nosed snakes, 2 California garden snakes, 2 lined racers, California king snake, desert gopher snake, banded gecko, giant rock Uta, 2 desert scaly lizards.
Mrs. Fisher, Washington, D. C., false chameleon.
Geo. Fleming and Wm. Lee, Washington, D. C., purple gallinule.
Forest Service, Department of Agriculture, Cherokee National Forest, Cleveland, Tenn., wild boar.
M. B. Foster, Orlando, Fla., worm snake.
Miss Harriet Freebey, Silver Spring, Md., barred owl.
Alonzo Gardner, Washington, D. C., alligator.
J. H. Gawlor, Washington, D. C., 2 Pekin ducks.
Frank Godwin, Capitol Heights, Md., banded rattlesnake.
Slad Goodnaugh, Fairfax, Va., 2 flying squirrels.
W. T. Grant, Richmond, Va., kinkajou.
Mrs. E. Gruening, Washington, D. C., 2 sparrow hawks.
Edw. Gwynn, Washington, D. C., horned lizard.
J. M. Hamlet, Portland, Oreg., 4 Oregon rattlesnakes.
Harold Hand, Washington, D. C., pied-billed grebe.
W. B. Harrison, Wildwood, Fla., worm snake.
Mrs. Daniel O. Hastings, Wilmington, Del., shama thrush.
W. H. Hawkins, Washington, D. C., red fox.
Mrs. H. E. Hay, Arlington, Va., 4 opossums.
Henry Holden, Washington, D. C., coatimundi.
A. Brazier Howell, Ruxton, Md., skunk.
Chas. B. Hunt, Hanksville, Utah, 4 midget rattlesnakes.

Walter Ilgenfritz, Washington, D. C., alligator.
M. Jacona, Washington, D. C., alligator.
Chester Jennings, Washington, D. C., Virginia rail.
Mrs. H. M. Kaiser, Berwyn, Md., opossum.
Mrs. F. Kass, Washington, D. C., grass paroquet.
Robert Keeling, Washington, D. C., zebra finch, cut-throat finch, Java sparrow.
Claude Keys, Washington, D. C., gray fox.
Jimmie Koehl, Hyattsville, Md., black widow spider.
Mr. Kunkel, Carlisle, Pa., 5 long-tailed salamanders.
Miss J. Lawless, Washington, D. C., snapping turtle.
Lt. L. H. Le Hardy, U. S. N., Galápagos iguana.
C. S. Little, Waycross, Ga., 2 alligators.
M. Little, Washington, D. C., snapping turtle.
O. M. Locke, New Braunfels, Tex., 3 nine-banded armadillos, 50 horned lizards.
James Lockheed, Washington, D. C., 2 rhesus monkeys.
H. P. Loding, Mobile, Ala., diamond-backed rattlesnake.
Norman Lowe, Rockville, Md., banded rattlesnake.
Dr. Bertha Lutz, Rio de Janeiro, Brazil, 3 horned frogs.
Dr. J. W. MacConnell, Davidson, N. C., red-crowned parrot.
Miss Barbara Madden, Washington, D. C., Cooper's hawk.
Wm. Mahaffey, South Carolina, eastern chipmunk.
Mrs. LeRoy Mark, Washington, D. C., rhesus monkey.
E. W. Marlowe, Jr., Washington, D. C., canary.
Menno Martin, Mishawaka, Ind., albino meadow mouse.
Dr. William R. Maxon, Washington, D. C., red-fronted parrot.
Maj. S. L. McCroskey, Washington, D. C., 2 grass paroquets.
A. E. McIlhenny, Avery Island, La., 10 Louisiana herons, 11 snowy egrets.
H. S. McKinley, Washington, D. C., 2 woodchucks or ground hogs.
Meems Bros. & Ward, New York, N. Y., 4 water moccasins.
Leroy Miller, Washington, D. C., horned grebe.
James Moody, Baltimore, Md., brown capuchin, 2 alligators.
H. G. Moore, Silver Spring, Md., American coot.
W. F. Morian, Washington, D. C., hog-nosed snake.
R. F. Mullen, Chevy Chase, Md., horned lizard.
J. P. Myers, Arlington, Va., barred owl.
John H. Newlin, Fort Hunt, Va., 3 red-tailed hawks.
Dr. G. K. Noble, New York, N. Y., 4 Surinam toads, 6 mouth-breeding fish.
Alva Nye, Jr., Washington, D. C., golden eagle.
Alvara Obregon, Mexico, 2 turtles.
T. W. Odom, Washington, D. C., bittern.
Mrs. Alma K. Palsgrove, Washington, D. C., 2 grass paroquets.
Petroleum Heat & Power Co., Washington, D. C., alligator.
Alan Philips, Baltimore, Md., piranha or cannibal fish.
Mrs. Barbara Polakov, Fairfax, Va., Javan macaque.
G. F. Pollock, Washington, D. C., red-headed lovebird.
W. R. Poore, Bethesda, Md., 2 skunks.
A. M. Raymond, Silver Spring, Md., horned grebe.
Miss M. L. Reavis, Washington, D. C., opossum.
T. M. Rees, Washington, D. C., alligator.
A. G. Reynolds, Washington, D. C., 2 prairie dogs.
Lowry Riggs, Rockville, Md., 3 loons.
D. F. Rinaca, Washington, D. C., great horned owl.

B. H. Roberts, Washington, D. C., 4 grass paroquets.
George A. Robinson, Falls Church, Va., 3 woodcocks.
D. L. Rodgers, Washington, D. C., Pekin duck.
Mrs. V. F. Rodrigo, Baltimore, Md., horned lizard.
E. J. Rosen, Alexandria, Va., red-tailed hawk.
J. S. Sallak, Washington, D. C., loon.
Robert Sanford, Washington, D. C., opossum.
R. F. Sappington, Chevy Chase, Md., barn owl.
Dr. Waldo Schmitt, Washington, D. C., 76 land hermit crabs, Galápagos hawk, James Island snake, Hood Island snake.
Loyd Schneider, Washington, D. C., 2 ospreys or fish hawks.
J. W. Scrivener, Washington, D. C., sparrow hawk.
H. T. Shannon, Washington, D. C., golden pheasant.
L. A. Sharp, Washington, D. C., 3 flying squirrels, 2 white-footed mice.
Miss Ola M. Shaw, Washington, D. C., double yellow-headed parrot.
Col. and Mrs. J. F. Siler, Washington, D. C., 2 troupials.
Allen Smith, Washington, D. C., garter snake.
G. B. Smith, Washington, D. C., 2 antelope squirrels.
Peggy Wood Smith, Washington, D. C., 2 Pekin ducks.
Robert D. Smith, Washington, D. C., horned grebe.
Mrs. Richard Southgate, Washington, D. C., troupial.
S. S. Spahr, Washington, D. C., blue jay.
Donald Sparrow, Washington, D. C., red-shouldered hawk.
E. Sullivan, Fredericksburg, Va., barred owl.
H. F. Thomas, Washington, D. C., woodchuck or ground hog.
H. O. Thompson, Washington, D. C., raccoon.
I. B. Tice, Washington, D. C., false chameleon.
R. E. Tiller, Washington, D. C., bluebird.
W. B. Tyrrell, Takoma Park, Md., barred owl.
U. S. Biological Survey through Roy Fugit and Jos. L. Crummett, Pendleton, Oreg., 6 Nevada long-eared foxes.
U. S. Marine Barracks, Quantico, Va., bald eagle.
Virginia Upton, Lanham, Md., 2 muscovy ducks.
E. G. Van Noy, Washington, D. C., alligator.
Miss Barbara Vierling, Silver Spring, Md., 3 guinea pigs.
J. E. Vincent, Washington, D. C., Cuban conure.
Mrs. C. B. Wagoner, Buckroe Beach, Va., 2 Amazon parrots.
Mrs. B. Waldron, Washington, D. C., painted bunting.
Mrs. Z. Wallace, Takoma Park, Md., screech owl.
J. L. Ward, Washington, D. C., woodchuck or ground hog.
Theo. A. Warner, Washington, D. C., flying squirrel.
Washington Post, Washington, D. C., opossum.
George Wech, Washington, D. C., double yellow-headed parrot.
A. P. Wheatley, Hyattsville, Md., 2 Pekin ducks.
Mrs. E. L. White, Washington, D. C., alligator.
Norman Winkler, Huntington, W. Va., hog-nosed snake.
Mrs. T. F. Woodward, Washington, D. C., white rabbit.
Holland Wyatt, Woodbridge, Va., blacksnake.
Mrs. Walter Wyatt, Washington, D. C., wood duck.

Births.—There were 48 mammals born and 15 birds hatched during the year.

MAMMALS

Scientific name	*Common name*	*Number*
Ammotragus lervia	Aoudad	4
Axis axis	Axis deer	7
Bison bison	American bison	3
Bos indicus	Zebu	1
Cervus elaphus	Red deer	2
Choeropsis liberiensis	Pigmy hippopotamus	1
Dama dama	Fallow deer	6
Felis onca	Jaguar	2
Hemitragus jemlahicus	Tahr	1
Magus maurus	Moor monkey	1
Macaca mordax	Javan monkey	2
Macaca mulatta	Rhesus monkey	1
Macaca nemistrina	Pig-tailed macaque	1
Ovis europaeus	Mouflon	1
Procyon lotor	Black raccoon	3
Pseudois nahura	Bharal or blue sheep	2
Sika nippon	Japanese deer	4
Taurotragus oryx	Eland	1
Thalarctos maritimus × *Ursus middendorffii*	Hybrid bear	2
Ursus arctos	European brown bear	1
Ursus gyas	Alaska peninsula bear	2

BIRDS

Chrysolophus pictus	Golden pheasant	5
Nycticorax nycticorax naevius	Black-crowned night heron	9
Spheniscus demersus	Jackass penguin	1

Exchanges.—A most interesting lot of South American animals were received on an exchange basis with the zoos at Buenos Aires and La Plata, Argentina. These were brought to the Park by the National Zoological Park-Argentina Expedition. Another important exchange was with the Cole Brothers Circus, in which the Zoo received a female hippopotamus and a male yak.

Purchases.—Specimens acquired by purchase and worthy of mention include a Malayan pangolin, one pair of Atlantic walruses, one pair of Bengal tigers, one pair of alpacas, a harpy eagle, and a pair of reticulated giraffes, the first of this species ever exhibited at the Park.

REMOVALS

Deaths.—Major losses during the year included one brown hyena, one Malayan pangolin, two walruses, one colobus monkey, a pronghorn antelope, and two shoebill storks. As in the past, all specimens of scientific value that died during the year were sent to the National Museum.

ANIMALS IN COLLECTION THAT HAD NOT PREVIOUSLY BEEN EXHIBITED

MAMMALS

Scientific name	*Common name*
Didelphis paraguayensis	Paraguay opossum.
Giraffa reticulata	Reticulated giraffe.
Hylochoerus meinertzhageni	Forest hog.
Odobenus rosmarus	Atlantic walrus.
Paramanis javanica	Malayan pangolin.
Potamochoerus porcus keniae	White-faced bush pig.

BIRDS

Anas braziliensis	Brazilian teal.
Anas spinicauda	Chilean pintail.
Buteo galapagoensis	Galápagos hawk.
Buteo melanoleucus	South American buzzard eagle.
Coracias caudatus lorti	Pink-throated roller.
Daptrius americanus	Carancho.
Eucorax comrii	Curl-crested manucode.
Furnarius rufus	Rufous ovenbird.
Leipoa ocellata	Mallee fowl.
Milvago chimango	Chimango.
Phimosus infuscatus	Dusky ibis.
Threskiornis spinicollis	Straw-necked ibis.
Trupialis defilippi	Military starling.

REPTILES

Boa occidentalis	Argentine boa.
Bothrops neuwiedii	Maximilian's viper.
Bufo arenarum	Argentine sand toad.
Calyptocephalus gayii	Chilean aquatic frog.
Dromicus dorsalis	James Island snake.
Dromicus hoodensis	Hood Island snake.
Pseudemys d'orbignyi	D'Orbigny's turtle.
Tupinambis rufescens	Red tegu lizard.

Statement of accessions

Class	Received from National Zoological Park-Argentine Expedition	Presented	Born	Received in exchange	Purchased	On deposit	Total
Mammals	35	82	48	11	53	12	241
Birds	177	125	15	7	22	7	353
Reptiles	98	121		3	102	17	341
Amphibians	6	8					14
Fishes		7			30	7	44
Arachnids		3					3
Mollusks		76					76
Total	316	422	63	21	207	43	1,072

Summary

Animals on hand July 1, 1938	2,754
Accessions during the year	1,072
Total animals in collection during year	3,826
Removal from collection by death, exchange, and return of animals on deposit	1,376
In collection June 30, 1939	2,450

Status of collection

Class	Species	Individuals	Class	Species	Individuals
Mammals	226	725	Insects	1	25
Birds	338	1,074	Mollusks	1	3
Reptiles	126	441	Crustaceans	1	9
Amphibians	23	89			
Fishes	25	79	Total	743	2,450
Arachnids	2	5			

ANIMALS IN THE NATIONAL ZOOLOGICAL PARK, JUNE 30, 1939

Mammals

MARSUPIALIA

		Number
Didelphidae:		
Didelphis paraguayensis	Paraguay opossum	1
Didelphis virginiana	Opossum	6
Metachirus opossum	Zorro or banana opossum	1
Dasyuridae:		
Sarcophilus ursinus	Tasmanian devil	2
Phalangeridae:		
Petaurus breviceps	Lesser flying phalanger	4
Trichosurus vulpecula	Vulpine opossum	1
Macropodidae:		
Dendrolagus inustus	Tree kangaroo	2
Dendrolagus ursinus × *D. inustus*	Hybrid tree kangaroo	1

INSECTIVORA

Erinaceidae:		
Atelerix hindei	East African hedgehog	3

CHIROPTERA

Vespertilionidae:		
Eptesicus fuscus	Large brown bat	2

CARNIVORA

Felidae:		
Acinonyx jubatus	Cheeta	2
Felis concolor	Puma	5
Felis leo	Lion	6
Felis ocreata	Uganda wildcat	1
Felis onca	Jaguar	5
	Black jaguar	2

CARNIVORA—continued

		Number
Felidae—Continued.		
Felis pardalis	Ocelot	1
Felis pardinoides	Lesser tiger cat	1
Felis pardus	Indian leopard	4
	Black Indian leopard	2
Felis pardus suahelicus	East African leopard	1
Felis tigris	Bengal tiger	2
Felis tigris longipilis	Siberian tiger	2
Felis tigris sondaicus	Sumatran tiger	4
Herpailurus yaguarondi	Eyra or yaguarondi	1
Lynx baileyi	Bailey's lynx	1
Lynx caracal	Caracal	1
Lynx rufus	Bay lynx	4
Lynx uinta	Bobcat	1
Neofelis nebulosa	Clouded leopard	1
Oncifelis geoffreyi	Geoffrey's cat	2
Profelis temmincki	Golden cat	3
Viverridae:		
Arctictis binturong	Binturong	4
Civettictis civetta	Civet	1
Genetta dongalana neumanni	Neumann's genet	1
Moschothera megaspila	Burmese civet	1
Paradoxurus hermaphrodytus	Small-toothed palm civet	2
Hyaenidae:		
Crocuta crocuta germinans	East African spotted hyena	1
Hyaena brunnea	Brown hyena	1
Canidae:		
Canis dingo	Dingo	2
Canis latrans	Albino coyote	1
	Coyote	8
Canis lairans × *domestica*	Coyote and dog hybrid	2
Canis lupus lycaon	Timber wolf	1
Canis lupus nubilus	Wolf	6
Canis rufus	Texas red wolf	5
Chrysocyon jubata	Maned wolf	1
Cuon javanicus sumatrensis	Sumatran wild dog	1
Dusicyon sp	South American fox	1
Dusicyon sp	South American fox	2
Urocyon cinereoargenteus	Gray fox	4
Vulpes fulva	Red fox	7
Vulpes macrotis nevadensis	Nevada long-eared fox	6
Procyonidae:		
Nasua narica	Coatimundi	10
Potos flavus	Kinkajou	4
Procyon cancrivorus	Crab-eating raccoon	1
Procyon lotor	Raccoon	9
	Raccoon (albino)	1
	Black raccoon	9
Bassariscidae:		
Bassariscus astutus	Ring-tail or cacomistle	2

		Number
Mustelidae:		
Arctonyx collaris	Hog badger	2
Charronia flavigula henricii	Asiatic marten	1
Galictis barbara barbara	White tayra	2
Grisonella huronax	Grison	2
Gulo luscus	Wolverine	2
Lutra canadensis vaga	Florida otter	2
Mellivora capensis	Ratel	1
Mephitis nigra	Skunk	11
Micraonyx leptonyx	Small-clawed otter	1
Mustela eversmanni	Ferret	3
Mustela noveboracensis	Weasel	1
Mustela vison vison	Mink	1
Ursidae:		
Euarctos americanus	American black bear	3
Euarctos emmonsii	Glacier bear	1
Helarctos malayanus	Malay or sun bear	1
Thalarctos maritimus	Polar bear	2
Thalarctos maritimus × *Ursus middendorffi.*	Hybrid bear	5
Ursus arctos	European brown bear	2
Ursus gyas	Alaska Peninsula bear	5
Ursus kidderi	Kidder's brown bear	1
Ursus middendorffi	Kodiak brown bear	4
Ursus sitkensis	Sitka brown bear	3
Ursus thibetanus	Himalayan bear	3

PINNIPEDIA

Otariidae:		
Zalophus californianus	California sea lion	2
Phocidae:		
Phoca richardii	Pacific harbor seal	3

PRIMATES

Lemuridae:		
Nycticebus coucang	Slow loris	4
Perodicticus potto	Potto	1
Callitrichidae:		
Leontocebus rosalia	Lion-headed or golden marmoset	3
Mico argentata	Black-tailed marmoset	1
Cebidae:		
Cebus apella	Brown capuchin	1
Cebus capucinus	White-throated capuchin	2
Cebus fatuellus	Weeping capuchin	3
Cebus sp	Gray capuchin	1
Cercopithecidae:		
Cercocebus fuliginosus	Sooty mangabey	6
Cercopithecus aethiops aethiops	Grivet monkey	1
Cercopithecus aethiops sabaeus	Green guenon	6
Cercopithecus diana	Diana monkey	1
Cercopithecus neglectus	De Brazza's guenon	1
Cercopithecus petaurista	Lesser white-nosed guenon	2
Cercopithecus pygerythra	Vervet guenon	1

PRIMATES—continued

		Number
Cercopithecidae—Continued.		
Cercopithecus roloway	Roloway monkey	1
Erythrocebus patas	Patas monkey	7
Macaca fuscata	Japanese monkey	1
Macaca lasiotis	Chinese macaque	2
Macaca mordax	Javan monkey	15
Macaca mulatta	Rhesus monkey	9
Macaca nemestrina	Pig-tailed macaque	7
Macaca silenus	Wanderoo monkey	1
Magus maurus	Moor monkey	4
Mandrillus leucophaeus	Drill	1
Mandrillus sphinx	Mandrill	2
Papio comatus	Chacma	2
Papio papio	West African baboon	1
Presbytis pyrrhus	Javan langur or lotong	1
Theropithecus gelada	Gelada baboon	1
Hylobatidae:		
Hylobates agilis	Sumatran gibbon	1
Hylobates lar pileatus	Black-capped gibbon	3
Symphalangus syndactylus	Siamang gibbon	1
Pongidae:		
Pan satyrus	Chimpanzee	3
Pongo abelii	Sumatran orangutan	2
Pongo pygmaeus	Bornean orangutan	1

RODENTIA

Sciuridae:		
Ammospermophilus leucurus	Antelope squirrel	2
Callosciurus melanops	Sumatran tricolored squirrel	2
Cynomys ludovicianus	Prairie dog	12
Glaucomys volans	Flying squirrel	7
Marmota flaviventris	Marmot or whistler	2
Marmota monax	Woodchuck or ground hog	3
Sciurus finlaysoni	Lesser white squirrel	3
Sciurus hoffmani	Hoffman's squirrel	2
Sciurus niger	Southern fox squirrel	8
Sciurus niger	Fox squirrel	1
Tamias striatus	Eastern chipmunk	2
Tamiasciurus hudsonicus	Red squirrel	1
Heteromyidae:		
Dipodomys deserti	Desert kangaroo rat	1
Dipodomys merriami	Merriam kangaroo rat	2
Perognathus parvus	Great Basin pocket mouse	2
Perognathus penicillatus	Desert pocket mouse	1
Jaculidae:		
Jaculus jaculus	Egyptian jerboa	1
Castoridae:		
Castor canadensis	Beaver	1
Cricetidae:		
Cricetomys gambianus	Gambia pouched rat	2
Neotoma floridana attwateri	Round-tailed wood rat	1
Onychomys sp	Grasshopper mouse	1
Peromyscus leucopus	White-footed mouse	24

RODENTIA—continued

		Number
Cricetidae—Continued.		
Sigmodon hispidus	Cotton rat	6
Synaptomys cooperi	Lemming mouse	1
Zapus hudsonius	Jumping mouse	1
Rhizomyidae:		
Nyctocleptes sumatrensis	Bamboo rat	1
Muridae:		
Rattus norvegicus (albino)	White rat	2
Hystricidae:		
Acanthion brachyurum	Malay porcupine	5
Atherurus africana	West African brush-tailed porcupine.	2
Hystrix galeata	East African porcupine	2
Thecurus sumatrae	Brush-tailed porcupine	1
Myocastoridae:		
Myocastor coypu	Nutria	11
Capromyidae:		
Capromys pilorides	Hutia	2
Cuniculidae:		
Cuniculus paca virgatus	Central American paca	2
Dasyproctidae:		
Dasyprocta croconota prymnolopha	Agouti	2
Chinchillidae:		
Lagostomus trichodactylus	Viscacha	2
Caviidae:		
Cavia porcellus	Domestic guinea pig	25
Cavia porcellus	Domestic guinea pig (angora breed)	2
Dolichotis magellanica	Patagonian cavy	7
Pediolagus salinicola	Dwarf cavy	3
Hydrochoeridae:		
Hydrochoerus hydrochoerus	Capybara	2

LAGOMORPHA

Leporidae:		
Oryctolagus cuniculus	Domestic rabbit	7

ARTIODACTYLA

Bovidae:		
Ammotragus lervia	Aoudad	15
Anoa depressicornis	Anoa	2
Bibos gaurus	Gaur	2
Bison bison	American bison	19
	Albino bison	1
Bos frontalis	Gayal	4
Bos indicus	Zebu	5
Boselaphus tragocamelus	Nilgai	1
Bubalus bubalis	Indian buffalo	1
Connochaetes gnu	White-tailed gnu	2
Connochaetes taurinus albojubatus	White-bearded gnu	2
Hemitragus jemlahicus	Tahr	4
Onotragus lechee	Lechee antelope	1
Oryx beisa annectens	Ibean beisa oryx	2
Ovis europaeus	Mouflon	3
Poephagus grunniens	Yak	4

ARTIODACTYLA—continued

		Number
Bovidae—Continued.		
Pseudois nahura	Bharal or blue sheep	4
Synceros caffer	African buffalo	2
Taurotragus oryx	Eland	4
Cervidae:		
Axis axis	Axis deer	15
Cervus canadensis	Wapiti	2
Cervus duvaucelii	Barasingha deer	3
Cervus elaphus	European red deer	17
Dama dama	Brown fallow deer	12
	White fallow deer	16
Muntiacus muntjak	Rib-faced or barking deer	1
Muntiacus sinensis	Chinese rib-faced deer	2
Odocoileus costaricensis	Costa Rican deer	1
Odocoileus virginianus	Virginia deer	2
Rusa moluccensis	Molucca deer	1
Sika nippon	Japanese deer	7
Tragulidae:		
Tragulus javanicus	Javan mouse deer	1
Giraffidae:		
Giraffa camelopardalis	Nubian giraffe	4
Giraffa reticulata	Reticulated giraffe	2
Camelidae:		
Lama glama	Llama	4
Lama huanacus	Guanaco	3
Lama pacos	Alpaca	2
Tayassuidae:		
Pecari angulatus	Collared peccary	4
Tayassu pecari	White-lipped peccary	2
Suidae:		
Babirussa alfurus	Babirussa	3
Hylochoerus meinertzhageni	Forest hog	1
Phacochoerus aethiopicus massaicus	East African wart hog	3
Potamochoerus porcus keniae	White-faced bush pig	1
Sus scrofa	European wild boar	1
Hippopotamidae:		
Choeropsis liberiensis	Pigmy hippopotamus	2
Hippopotamus amphibius	Hippopotamus	2

PERISSODACTYLA

Equidae:		
Equus grevyi	Grevy's zebra	1
Equus grevyi-asinus	Zebra-ass hybrid	1
Equus grevyi-caballus	Zebra-horse hybrid	1
Equus kiang	Asiatic wild ass or kiang	2
Equus przewalskii	Mongolian wild horse	3
Equus quagga chapmani	Chapman's zebra	8
Equus zebra	Mountain zebra	2
Tapiridae:		
Acrocodia indica	Asiatic tapir	1
Tapirella bairdii	Central American tapir	1
Tapirus terrestris	South American tapir	2
Rhinocerotidae:		
Diceros bicornis	Black rhinoceros	1

PROBOSCIDEA

		Number
Elephantidae:		
Elephas sumatranus	Sumatran elephant	1
Loxodonta africana oxyotis	African elephant	1

EDENTATA

Choloepodidae:		
Choloepus didactylus	Two-toed sloth	2
Dasypodidae:		
Dasypus novemcinctus	Nine-banded armadillo	3
Euphractus sexcinctus	Six-banded armadillo	1
Myrmecophagidae:		
Myrmecophaga jubata	Giant anteater	1

BIRDS

STRUTHIONIFORMES

Struthionidae:		
Struthio camelus	South African ostrich	1

RHEIFORMES

Rheidae:		
Rhea americana	Common rhea or nandu	7
	White rhea	3

CASUARIIFORMES

Casuariidae:		
Casuarius bennetti	Bennett's cassowary	1
Casuarius sp	cassowary	1
Casuarius sp	cassowary	1
Casuarius unappendiculatus	Single-wattled cassowary	1
Dromiceiidae:		
Dromiceius novaehollandiae	Common emu	2

SPHENISCIFORMES

Spheniscidae:		
Spheniscus demersus	Jackass penguin	6

PELECANIFORMES

Pelecanidae:		
Pelecanus californicus	California brown pelican	2
Pelecanus conspicillatus	Australian pelican	1
Pelecanus erythrorhynchos	American white pelican	5
Pelecanus erythrorhynchos × *P. occidentalis.*	American white and brown pelican (hybrid).	1
Pelecanus occidentalis	Brown pelican	2
Pelecanus onocrotalus	European pelican	2
Pelecanus roseus	Rose-colored pelican	2
Sulidae:		
Morus bassanus	Gannet	1
Sula granti	Blue-footed booby	1
Phalacrocoracidae:		
Phalacrocorax auritus albociliatus	Farallon cormorant	2
Phalacrocorax auritus floridanus	Florida cormorant	1

PELECANIFORMES—continued

		Number
Anhingidae:		
Anhinga anhinga	Anhinga	1
Fregatidae:		
Fregata ariel	Lesser frigate bird	2

CICONIIFORMES

Ardeidae:		
Ardea herodias	Great blue heron	1
Ardea-herodias × A. occidentalis	Heron hybrid	1
Ardea occidentalis	Great white heron	1
Botaurus lentiginosus	American bittern	1
Casmerodius albus egretta	American egret	1
Egretta thula	Snowy egret	5
Notophoyx novaehollandiae	White-faced heron	1
Nycticorax nycticorax naevius	Black-crowned night heron	6
Cochleariidae:		
Cochlearius cochlearius	Boatbill heron	3
Scopidae:		
Scopus umbretta	Hammerhead	1
Ciconiidae:		
Dissoura episcopus	Woolly-necked stork	1
Ephippiorhynchus senegalensis	Saddle-billed stork	1
Euxenura galatea	Maguari stork	3
Ibis cinereus	Malay stork	2
Jabiru mycteria	Jabiru	2
Leptoptilus crumeniferus	Marabou	1
Leptoptilus dubius	Indian adjutant	1
Leptoptilus javanicus	Lesser adjutant	2
Mycteria americana	Wood ibis	1
Threskiornithidae:		
Ajaia ajaja	Roseate spoonbill	1
Guara alba	White ibis	3
Guara alba × G. rubra	Hybrid ibis (scarlet and white)	1
Guara rubra	Scarlet ibis	2
Phimosus infuscatus	Dusky ibis	1
Threskiornis aethiopica	Sacred ibis	1
Threskiornis melanocephala	Black-headed ibis	2
Threskiornis spinicollis	Straw-necked ibis	2
Phoenicopteridae:		
Phoenicopterus chilensis	Chilean flamingo	21

ANSERIFORMES

Anhimidae:		
Chaunacristata	Crested screamer	10
Anatidae:		
Aix sponsa	Wood duck	17
Alopochen aegyptiacus	Egyptian goose	2
Anas brasiliensis	Brazilian teal	2
Anas domestica	Pekin duck	10
Anas platyrhynchos	Mallard duck	45
Anas rubripes	Black or dusty mallard	2
Anser albifrons	American white-fronted goose	4
Branta bernicla	Brant	2
Branta canadensis	Canada goose	6

ANSERIFORMES—continued

Anatidae—Continued.		Number
Branta canadensis minima	Cackling goose	1
Branta canadensis occidentalis	White-cheeked goose	15
Branta leucopsis	Barnacle goose	1
Cairina moschata	Muscovy duck	2
Casarca variegata	Paradise duck	1
Cereopsis novaehollandiae	Cereopsis or Cape Barren goose	1
Chen atlantica	Snow goose	5
Chen caerulescens	Blue goose	4
Chloephaga poliocephala	Ashy-headed upland goose	2
Coscoroba coscoroba	Coscoroba	5
Cygnopsis cygnoides	Chinese goose	1
Cygnus columbianus	Whistling swan	3
Cygnus melancoriphus	Black-necked swan	11
Cygnus olor	Mute swan	2
Dafila acuta	Pintail	1
Dafila spinicauda	Chilean pintail	1
Dendrocygna arborea	Black-billed duck	3
Dendrocygna autumnalis	Black-bellied tree duck	2
Dendrocygna viduata	White-faced tree duck	5
Mareca americana	Bald pate	1
Philacte canagica	Emperor goose	4
Plectropterus gambensis	Spur-winged goose	1

FALCONIFORMES

Cathartidae:		
Cathartes aura	Turkey vulture	3
Cathartes aura × *Coragyps atratus*	Black vulture and turkey vulture hybrid	1
Coragyps atratus	Black vulture	1
Gymnogyps californianus	California condor	3
Sarcoramphus papa	King vulture	2
Vultur gryphus	South American condor	3
Accipitridae:		
Accipiter cooperi	Cooper's hawk	1
Aegypius monachus	Cinereous vulture	1
Aquila chrysaetos	Golden eagle	1
Buteo borealis	Red-tailed hawk	3
Buteo galapagoensis	Galápagos hawk	1
Buteo lineatus	Red-shouldered hawk	8
Buteo melanoleucus	South American buzzard eagle	2
Buteo swainsoni	Swainson's hawk	2
Gypaetus barbatus grandis	Lammergeyer	1
Gyps rueppelli	Ruppell's vulture	1
Haliaeetus leucocephalus	Bald eagle	13
Haliaeetus leucocephalus alascanus	Alaskan bald eagle	2
Haliastur indus	Brahminy kite	3
Harpia harpya	Harpy eagle	1
Milvago chimango	Chimango	2
Milvus migrans	Yellow-billed kite	1
Pandion haliactus carolinensis	Osprey or fish hawk	3
Torgos tracheliotus	African eared vulture	1
Uroaetus audax	Wedge-tailed eagle	1

FALCONIFORMES—continued

		Number
Falconidae:		
Daptrius americanus	Carancho	3
Falco sparverius	Sparrow hawk	3
Polyborus cheriway	Audubon's caracara	2
Polyborus plancus	South American caracara	1

GALLIFORMES

Megapodiidae:		
Alectura lathami	Australian brush turkey	2
Leipoa ocellata	Mallee fowl	1
Megapodius freycineti	Molucca megapode	1
Cracidae:		
Crax rubra	Panama curassow	1
Crax sclateri	Sclater's curassow	4
Mitu mitu	Razor-billed curassow	3
Mitu salvini	Salvin's curassow	1
Phasianidae:		
Argusianus argus	Argus pheasant	3
Calopezus elegans	Crested tinamou or martineta	23
Catreus wallichii	Cheer pheasant	1
Chrysolophus amherstiae	Lady Amherst's pheasant	1
Chrysolophus pictus	Golden pheasant	5
Coturnix coturnix	Migratory quail	21
Excalfactoria chinensis	Blue-breasted button quail	7
Gallus sp. × *Numida galeata*	Chicken and guinea fowl hybrid	2
Gennaeus lineatus	Lineated pheasant	1
Gennaeus nycthemerus	Silver pheasant	1
Hierophasis swinhoii	Swinhoe's pheasant	1
Lophophorus impeyanus	Himalayan impeyan pheasant	1
Lophura rubra	Malayan fire-back pheasant	1
Nothura maculosa	Spotted tinamou	18
Pavo cristatus	Peafowl	6
Pavo muticus	Green peafowl	2
Phasianus torquatus	Ring-neck pheasant	1
	White ring-necked pheasant	2
Phasianus torquatus formosanus	Formosan ring-necked pheasant	1
Phasianus versicolor	Green Japanese pheasant	1
Polyplectron napoleonis	Palawan peacock pheasant	2
Syrmaticus reevesi	Reeves' pheasant	1

GRUIFORMES

Gruidae:		
Anthropoides virgo	Demoiselle crane	8
Balearica pavonina	West African crowned crane	1
Balearica regulorum gibbericeps	East African crowned crane	1
Grus canadensis canadensis	Little brown crane	1
Grus canadensis tabida	Sandhill crane	1
Grus leucauchen	White-naped crane	1
Grus leucogeranus	Siberian crane	2
Psophiidae:		
Psophia crepitans	Gray-backed trumpeter	1
Rallidae:		
Gallinula chloropus cachinnans	Florida gallinule	2
Gallinula chloropus orientalis	Sumatran gallinule	3

GRUIFORMES—continued

		Number
Rallidae—Continued.		
Limnocorax flavirostra	African black rail	2
Porphyrio poliocephalus	Gray-headed porphyrio	2
Rallus philippensis australis	Australian rail	1
Eurypygidae:		
Eurypyga helias	Sun bittern	2
Cariamidae:		
Cariama cristata	Cariama or seriama	2
Otididae:		
Otis cafra	Denham's bustard	1
Otis caffra jacksoni	Jackson's bustard	1

CHARADRIIFORMES

Haematopodidae:		
Haematopus ostralegus	European oyster catcher	2
Charadriidae:		
Bedonopterus chilensis	Chilean lapwing	2
Scolopacidae:		
Philomachus pugnax	Ruff	1
Laridae:		
Larus argentatus	Herring gull	1
Larus delawarensis	Ring-billed gull	1
Larus glaucescens	Glaucous-winged gull	1
Larus novaehollandiae	Silver gull	24

COLUMBIFORMES

Columbidae:		
Caloenas nicobarica	Nicobar pigeon	5
Chalcophaps indica	Emerald dove	1
Columba livia (domestic)	Archangel pigeon	2
Columba livia (domestic)	Fan-tailed pigeon	1
Columba maculosa	Spot-winged pigeon	1
Columba palumbus	Wood pigeon	1
Columba picazuro	Picazuro pigeon	2
Dendrophassa vernans griseicapilla	Sumatran fruit pigeon	4
Ducula aenea	Green imperial pigeon	1
Eutreron pulchella	Purple-capped fruit dove	1
Gallicolumba luzonica	Bleeding-heart dove	5
Goura cristata	Sclater's crowned pigeon	5
Goura victoria	Victoria crowned pigeon	3
Lamprotreron jambu	Pink-headed fruit pigeon	1
Leptotila rufaxilla	Scaled pigeon	2
Muscadivores paulina	Celebian imperial pigeon	2
Myristicivora bicolor	Pied imperial pigeon	2
Streptopelia chinensis	Asiatic collared dove	26
Streptopelia risoria	Ring-necked dove	4
Turtur risorius	Turtle dove	2

PSITTACIFORMES

Psittacidae:		
Agapornis sp	Red-headed lovebird	1
Agapornis lilianae	Nyassa lovebird	3
Amazona aestiva	Amazon or blue-fronted parrot	3
Amazona albifrons	White-fronted parrot	1

PSITTACIFORMES—continued

Psittacidae—Continued.		Number
Amazona amazonica	Orange-winged parrot	2
Amazona arausiaca	Boquet's parrot	1
Amazona auropalliata	Yellow-naped parrot	9
Amazona festiva	Festive parrot	1
Amazona leucocephala	Cuban parrot	3
Amazona ochrocephala	Yellow-head parrot	3
Amazona ochroptera	Yellow-shouldered parrot	3
Amazona oratrix	Double yellow-head parrot	7
Amazon viridigenalis	Red-crowned parrot	1
Anodorhynchus hyacinthinus	Hyacinthine macaw	1
Ara ararauna	Yellow and blue macaw	1
Ara chloroptera	Red and blue macaw	1
Ara macao	Red, blue, and yellow macaw	2
Ara macavuanna-manilata	Illiger's macaw	2
Ara militaria	Mexican green macaw	1
Ara severa	Severe macaw	1
Aratinga euops	Cuban conure	1
Brotogeris jugularis	Tovi paroquet	3
Calyptorhynchus magnificus	Banksian cockatoo	1
Coracopsis nigra	Lesser vasa parrot	1
Cyanopsittacus spixi	Spix's macaw	2
Domicella flavopalliata	Red lory	3
Eclectus pectoralis	Eclectus parrot	2
Eolophus roseicapillus	Roseate cockatoo	1
Eos rubra	Red lory	1
Eupsittula aurea	Golden-crowned paroquet	1
Eupsittula canicularis	Petz paroquet	1
Kakatoe alba	White cockatoo	2
Kakatoe citrinocristata	Orange-crested cockatoo	2
Kakatoe galerita	Large sulphur-crested cockatoo	4
Kakatoe leadbeateri	Leadbeaters' cockatoo	2
Kakatoe moluccensis	Great red-crested cockatoo	1
Kakatoe sulphurea	Lesser sulphur-crested cockatoo	5
Kakatoe tenuirostris	Slender-billed cockatoo	1
Lorius domicella	Rajah lory	2
Lorius garrulus	Lory	3
Melopsittacus undulatus	Grass parakeet	7
Microglossus aterrimus	Great black cockatoo	1
Myopsitta monachus	Quaker paroquet	1
Nandayus nanday	Nanday paroquet	1
Nestor notabilis	Kea	3
Pionites xanthomera	Amazonian caique	2
Pionus menstruus	Blue-headed parrot	1
Psittacula eupatria	Red-shouldered paroquet	4
Psittacula krameri	Kramer's paroquet	6
Psittacula longicauda	Long-tailed paroquet	1
Psittacula nepalensis	Nepalese paroquet	1
Psittacus erithacus	African gray parrot	1
Tanygnathus megalorhynchus	Great-billed parrot	1
Tanygnathus muelleri	Mueller parrot	1
Trichoglossus cyanogrammus	Green-naped lory	1
Trichoglossus haematod	Ceram lory	1

CUCULIFORMES

		Number
Cuculidae:		
Centropus sinensis	Sumatran coucal	1
Eudynamis scolopaceus	Koel	1

STRIGIFORMES

Strigidae:		
Bubo virginianus	Great horned owl	8
Ketupa ketupu	Malay fish owl	1
Otus asio	Screech owl	3
Strix varia varia	Barred owl	17

CAPRIMULGIFORMES

Podargidae:		
Podargus strigoides	Tawny frogmouth	1

CORACIIFORMES

Alcedinidae:		
Dacelo gigas	Kookaburra	2
Halcyon pyrrhopygius	Red-backed kingfisher	1
Halcyon sanctus	Sacred kingfisher	4
Momotidae:		
Momotus lessoni	Motmot	1
Bucerotidae:		
Buceros rhinoceros	Rhinoceros hornbill	2
Bucorvus abyssinicus	Abyssinian ground hornbill	2
Dichoceros bicornis	Concave casque hornbill	1
Hydrocissa convexa	Pied hornbill	1

PICIFORMES

Capitonidae:		
Thereiceryx zeylandicus	Streaked barbet	2
Ramphastidae:		
Ramphastos ariel	Ariel toucan	1
Ramphastos piscivorus	Toco toucan	1

PASSERIFORMES

Furnariidae:		
Furnarius rufus	Rufous ovenbird	20
Tyrannidae:		
Pitangus sulphuratus	Kiskadee flycatcher	1
Pittidae:		
Pitta brachyura	Indian pitta	1
Corvidae:		
Aphelocoma californica woodhousei	Woodhouse's jay	1
Calocitta formosa	Mexican magpie jay	1
Cissa chinensis	Chinese cissa	2
Corvus albus	White-breasted crow	2
Corvus brachyrhynchos	American crow	5
Corvus coronoides	Australian crow	1
Corvus cryptoleucus	White-necked raven	5
Corvus insolens	Indian crow	3
Cyanocitta cristata	Blue jay	2
Cyanocorax cyanopogon	White-naped jay	2
Gymnorhina hypoleuca	White-backed piping crow	3
Pica nuttallii	Yellow-billed magpie	2

PASSERIFORMES—continued

		Number
Corvidae—Continued.		
Pica pica hudsonia	American magpie	2
Urocissa occipitalis	Red-billed blue magpie	1
Xanthoura luxuosa guatemalensis	Guatemalan green jay	1
Paradiseidae:		
Ailuroedus crassirostris	Australian catbird	1
Eucorax comrii	Curl-crested manucode	1
Ptilonorhynchus violaceus	Satin bowerbird	3
Seleucides niger	12-wired bird of paradise	1
Uranornis rubra	Red bird of paradise	7
Pycnonotidae:		
Molpastes haemorrhous	Black-headed bulbul	1
Otocompsa jocosus	Red-eared bulbul	1
Pycnonotus analis	Yellow-vented bulbul	2
Pycnonotus bindentatus	Orange-spotted bulbul	3
Rubigula dispar	Red-throated bulbul	2
Trachycomus zeylonicus	Yellow-crowned bulbul	1
Turdidae:		
Kittacincla malabarica	Shama thrush	1
Mesia argentauris	Silver-eared mesia	2
Mimocichla rubripes	Western red-legged thrush	4
Myadestes unicolor	Slate-colored solitaire	1
Turdus grayi	Bonaparte's thrush	1
Laniidae:		
Lanius dorsalis	Teita fiscal shrike	2
Sturnidae:		
Aplonis chalybea	Glossy aplonis	2
Cosmopsaris regius	Splendid starling	3
Creatophora cinerea	Wattled starling	2
Galeopsar salvadorii	Crested starling	1
Gracula religiosa	Southern hill mynah	1
Trupialis defilippi	Military starling	16
Compsothlypidae:		
Seiurus aurocapillus	Ovenbird	1
Ploceidae:		
Amadina fasciata	Cut-throat finch	1
Coliuspasser ardens	Red-necked whydah	2
Diatropura procne	Giant whydah	6
Erythrura prasina	Long-tailed munia	3
Munia maja	White-headed munia	26
Munia molucca	Black-throated munia	6
Munia oryzivora	Java sparrow	1
	White Java sparrow	2
Munia punctulatus	Rice bird or nutmeg finch	9
Ploceus baya	Baya weaver	6
Ploceus intermedius	Black-cheeked weaver	2
Ploceus rubiginosus	Chestnut-breasted weaver	7
Poephila acuticauda	Long-tailed finch	7
Poephila gouldiae	Gouldian finch	3
Quelea sanguinirostris intermedia	Southern masked weaver finch	12
Steganopleura bichenovii	Banded finch	5
Steganura paradisea	Paradise whydah	7
Taeniopygia castanotis	Zebra finch	2

PASSERIFORMES—continued

		Number
Icteridae:		
Agelaius assimilis	Cuban red-winged blackbird	5
Gymnomystax mexicanus	Giant oriole	2
Icterus icterus	Troupial	5
Molothrus ater	Cowbird	1
Psomocolax oryzivora	Rice grackle	1
Xanthocephalus xanthocephalus	Yellow-headed blackbird	4
Thraupidae:		
Thraupis cana	Blue tanager	2
Fringillidae:		
Amandava amandava	Strawberry finch	36
Carduelis carduelis	European goldfinch	1
Fringilla montifringilla	Brambling finch	1
Melopyrrha nigra	Cuban bullfinch	1
Paroaria cucullata	Brazilian cardinal	1
Pheucticus tibialis	Yellow grosbeak	1
Richmondena cardinalis cardinalis	Eastern cardinal	2
Serinus canarius	Canary	1
Sicalis minor	Lesser yellow finch	6
Sporophila aurita	Hick's seed-eater	2
Sporophila gutturalis	Yellow-bellied seed-eater	2
Urolonchа leucogastroides	Society finch	1
Volatinia jacarini	Blue-black grassquit	1

REPTILES

LORICATA

Crocodylidae:		
Alligator mississipiensis	Alligator	17
Alligator sinensis	Chinese alligator	3
Caiman latirostris	Broad-snouted caiman	1
Caiman sclerops	Spectacled caiman	3
Crocodylus acutus	American crocodile	1
Crocodylus cataphractus	West African crocodile	1
Crocodylus porosus	Salt-water crocodile	1
Osteolaemus tetraspis	Broad-nosed crocodile	1
Tomistoma schlegeli	Malayan gavial	7

SQUAMATA

Agamidae:		
Acanthosaura armata	Armed tree lizard	1
Physignathus lesueurii	Lesueur's water dragon	2
Iguanidae:		
Anolis carolinensis	False chameleon	14
Anolis equestris	Giant anolis	7
Conolophus subcristatus	Galápagos iguana	1
Iguana iguana	Iguana	1
Leiocephalus cubensis	Cuban curl-tailed lizard	1
Phrynosoma cornutum	Horned lizard	8
Sceloporus magister	Desert scaly lizard	1
Sceloporus torquatus	Scaly lizard	1
Sceloporus undulatus	Fence lizard	3
Anguidae:		
Ophisaurus apus	European glass snake	1
Ophisaurus ventralis	Glass snake	1

SQUAMATA—continued

		Number
Gerrhosauridae:		
Gerrhosaurus validus	Robust plated lizard	1
Helodermatidae:		
Heloderma horridum	Mexican beaded lizard	2
Heloderma suspectum	Gila monster	8
Teiidae:		
Tupinambis nigropunctatus	Tegu lizard	2
Tupinambis rufescens	Red tegu lizard	1
Tupinambis teguixin	Yellow tegu lizard	13
Scincidae:		
Egernia cunninghami	Cunningham's skink	2
Eumeces fasciatus	Red-headed skink	1
Tiliqua nigrolutea	Mottled lizard	1
Tiliqua scincoides	Blue-tongued lizard	2
Varanidae:		
Varanus griseus	Gray monitor	1
Varanus komodoensis	Komodo dragon	1
Varanus niloticus	African monitor	1
Varanus salvator	Sumatran monitor	12

OPHIDIA

Boidae:		
Boa cookii	Cook's tree boa	1
Boa occidentalis	Southern boa constrictor	2
Constrictor constrictor	Boa constrictor	6
Constrictor imperator	Emperor boa	2
Epicrates cenchris	Rainbow boa	10
Epicrates crassus	Salamanta	2
Epicrates striatus	Haitian boa	1
Eryx johni	Indian sand boa	1
Tropidophis melanurus	Cuban boa	1
Pythonidae:		
Python curtus	Blood python	1
Python molurus	Indian rock python	3
Python regius	Ball python	1
Python reticulatus	Regal python	4
Python sebae	African rock python	3
Python variegatus	Carpet python	1
Colubridae:		
Alsophis angulifer	Jubo or culebra	6
Boiga dendrophila	Mangrove snake	1
Cyclagras gigas	Cobra-de-Paraguay	3
Diadophis punctatus	Ring-necked snake	1
Drymarchon corais couperi	Indigo snake	4
Drymobius bifossatus	Jararacussu do brejo	6
Elaphe guttata	Corn snake	4
	Night snake	1
	Indigo snake	1
Elaphe obsoleta	Pilot Snake	8
Elaphe quadrivittata	Chicken snake	2
Elaphe vulpina	Fox snake	1
Heterodon contortrix	Hog-nosed snake	2
Hypsiglena ochrorhynchus		1

OPHIDIA—continued

		Number
Colubridae—Continued.		
Lampropeltis triangulum	Milk snake	1
Natrix sp	Water snake	6
Natrix cyclopion	Water snake	2
Philodryas schottii	Parelheira	3
Thamnophis ordinoides	California garter snake	1
Thamnophis sirtalis concinnus	Pacific garter snake	6
Thamnophis sirtalis sirtalis	Garter snake	8
Xendon merremii	Boipeva	7
Elapidae:		
Naja hannah	King cobra	2
Naja tripudians sumatrana	Sumatran black-hooded cobra	1
Naja tripudians (var.)	Spectacled cobra	3
Naja tripudians (var.)	Siamese black-hooded cobra	3
Crotalidae:		
Agkistrodon mokasen	Copperhead snake	2
Agkistrodon piscivorus	Water moccasin	6
Bothrops neuwiedii	Maximilian's viper	2
Crotalus adamanteus	Florida diamond-backed rattlesnake.	2
Crotalus cinereous	Texas rattlesnake	3
Crotalus horridus	Banded rattlesnake	3
Crotalus oreganus	Oregon rattlesnake	3
Sistrurus catenatus catenatus	Massasauga	12
Sistrurus miliarius	Pigmy rattlesnake	2
Viperidae:		
Atheris chlorechis	West African tree viper	2

TESTUDINATA

Chelydidae:		
Batrachemys nasuta	South American side-necked turtle.	3
Chelodina longicollis	Australian snake-necked turtle	4
Chelys fimbriata	Matamata turtle	1
Hydraspis sp	South American snake-necked turtle.	4
Hydromedusa tectifera	South American snake-necked turtle.	17
Platysternidae:		
Platemys platycephala	Flat-headed turtle	1
Platysternum megacephalum	Large-headed Chinese turtle	2
Pelomedusidae:		
Pelomedusa galeata	Common African water tortoise	2
Podocnemis expansa	South American river tortoise	1
Kinosternidae:		
Kinosternon sp	Central American musk turtle	4
Kinosternon subrubrum	Musk turtle	1
Chelydridae:		
Chelydra serpentina	Snapping turtle	2
Macrochelys temminckii	Alligator snapping turtle	1
Testudinidae:		
Chrysemys picta	Painted turtle	8
Clemmys guttata	Spotted turtle	2

TESTUDINATA—continued

Testudinidae—Continued.		Number
Clemmys insculpta	Wood tortoise	1
Clemmys muhlenbergii	Muhlenberg's tortise	1
Cyclemys amboinensis	Kura kura box turtle	14
Deirochelys reticularia	Chicken tortoise	1
Emys blandingii	Blanding's turtle	1
Gopherus polyphemus	Gopher turtle	1
Graptemys geographica	Geographic turtle	3
Malaclemmys centrata	Diamond-back terrapin	7
Pseudemys concinna	Cooter	4
Pseudemys decussata	Haitian terrapin	1
Pseudemys d'orbignyi	D'Orbigny's turtle	3
Pseudemys elegans	Cumberland terrapin	3
Pseudemys floridana	Florida terrapin	2
Pseudemys ornata	----------	2
Pseudemys rubriventris	Red-bellied turtle	1
Pseudemys rugosus	Cuban terrapin	1
Terrapene carolina	Box tortoise	6
Testudo chilensis	----------	25
Testudo denticulata	----------	10
Testudo emys	Sumatran land tortoise	1
Testudo ephippium	Duncan Island tortoise	2
Testudo hoodensis	Hood Island tortoise	3
Testudo tornieri	Soft-shelled land tortoise	4
Testudo vicina	Albemarle Island tortoise	1
Trionychidae:		
Amyda ferox	Soft-shelled turtle	7
Trionyx cartilagineus	Asiatic soft-shelled turtle	1

AMPHIBIA

CAUDATA

Salamandridae:		
Triturus pyrrhogaster	Red-bellied Japanese newt	2
Triturus viridescens	Common newt	2
Triturus vulgaris	Salamander	1
Ambystomidae:		
Ambystoma tigrinum	Tiger salamander	1
Amphiumidae:		
Amphiuma means	Blind eel or Congo snake	2
Amphiuma tridactylum	Blind eel or Congo snake	1
Megalobatrachus japonicus	Giant salamander	1
Cryptobranchidae:		
Crytobranchus alleganiensis	Hellbender	4

SALIENTIA

Dendrobatidae:		
Atelopus sp	Golden-striped frog	1
Dendrobates auratus	Arrow-poison frog	10
Bufonidae:		
Bufo americanus	Common American toad	2
Bufo arenarum	Argentine sand toad	1

SALIENTIA—continued

Bufonidae—Continued.		Number
Bufo empusus	Sapo de concha	14
Bufo marinus	Marine toad	11
Bufo peltocephalus	Cuban giant toad	6
Ceratophrydae:		
Ceratophrys ornata	Horned frog	3
Ceratophrys varius	Horned frog	4
Hylidae:		
Hyla caerulea	Australian tree frog	3
Hyla cinerea	Florida tree frog	1
Hyla septentrionalis	Cuban tree frog	1
Pipidae:		
Calyptocephalus gayii	Chilean aquatic frog	2
Pipa americana	Surinam toad	13
Ranidae:		
Rana clamitans	Green frog	3

FISHES

Acanthopthalmus kuhlii	Banded loach	4
Anguilla rostrata	Common eel	3
Anostomus anostomus		1
Barbus laterstrigga		1
Barbus partipentazona	Red-finned barb	10
Carnegiella strigata	Striped hatchet fish	2
Corydoras melanistius	Armored catfish	1
Elecrophorus electricus	Electric eel	5
Hemigrammus unilineatus		1
Hemiodus sp		1
Hyphessobrycon innesi	Neon tetra fish	12
Hyphessobrycon sp		1
Kryptopterus bicirrhus	Glass catfish	2
Lebistes reticulatus	Guppy	12
Lepidosiren paradoxa	South American lungfish	3
Leporinus fasciata	Leopard fish	1
Monocirrhus polyacanthus	Leaf fish	4
Pantodon buchholzi	Butterfly fish	4
Platypoecilus maculatus	Goldplaties	2
Pristella riddlei		1
Protopterus annectens	African lungfish	2
Serrasalmus ternetzi	Piranha or cannibal fish	1
Tilapia sp	Mouth-breeding fish	3
Trichogaster leeri	3-spot gourami	1
Xiphophorus helleri	Sword-tail	1

ARACHNIDS

Eurypelma sp	Tarantula	4
Latrodectus mactans	Black widow spider	1

INSECTS

Blabera sp	Giant cockroach	25

MOLLUSKS

		Number
Achatina variegata	Giant land snail	3

CRUSTACEANS

Coenobita clypeatus	Land hermit crab	9

Respectfully submitted.

W. M. MANN, *Director.*

Dr. C. G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 8

REPORT ON THE ASTROPHYSICAL OBSERVATORY

SIR: I have the honor to submit the following report on the activities of the Astrophysical Observatory for the fiscal year ended June 30, 1939:

WORK AT WASHINGTON

RECOMPUTATIONS

The main business was the recomputation of all solar-constant values since 1923, under the direction of L. B. Aldrich, referred to in the two preceding reports. By the end of the fiscal year new results had been computed for all available days since 1923 at all stations. But the final corrections and general discussion still remained to be done. Corrections had been applied, however, for sky-brightness, ozone absorption, and all other conditions for the results of Montezuma and St. Katherine for the years 1933 to 1939, so that these values are definitive, except for the final reduction to a uniform scale at all stations. This is to be decided upon when all the work is done. It is expected that the entire recomputation will be wholly completed by October 1939. A publication of the revised work will afterward be made, funds for which have been generously provided by John A. Roebling.

The improvement in accuracy resulting from the revision is very apparent when comparing Montezuma and St. Katherine daily results of the years 1933 to 1939, now practically final. Part of this improvement results from the elimination of the radiation received by pyrheliometers from the sky near the sun. We had always hitherto treated this as negligible, but it was found to be a quantity ranging up to about 0.5 percent and variable with the haziness prevailing. A method was devised and applied for determining this sky radiation. Its elimination from all the pyrheliometric observations since 1923 has been a considerable task, and has prevented the completion of the revision of the solar-constant work by January 1939 as was stated in last year's report to be expected.

A CONTROVERSY

The Director spent much time in preparing a suitable reply to an article by Dr. M. M. Paranjpe (Quart. Journ. Roy. Met. Soc., July 1938). That author concluded:

The variations observed in the solar constant by the Astrophysical Observatory of the Smithsonian Institute during the last 30 years are mainly due to the defects in the methods of determining the solar constant. If this conclusion is accepted the subsequent work based on the supposed variability of the solar constant is not valid.

Dr. Paranjpe's paper was read at a meeting of the Royal Meteorological Society and favorably received and commented upon by several of the principal meteorologists of Great Britain.

Dr. Abbot's reply (Quart. Journ. Roy. Met. Soc., April 1939) is abstracted as follows:

The author cites five recent papers containing many evidences of solar change ignored by critics. Chief among them, and in the author's opinion unanswerable, are evidences that day to day solar changes profoundly influence temperatures. Between 1924 and 1935 were found 320 dates, the beginnings of sequences of observed rise or of fall of solar radiation. The average march of departures from normal temperatures in four widely separated cities shows opposite trends for 16 days following, respectively, these sequences of rising and falling solar radiation. The separation of temperatures thus produced reaches from 10° to 25° F. Similar curves of temperature departure are found, on the average, in the years 1924 to 1930, to those found in the years 1931 to 1935. Selecting 46 cases of especially large solar changes observed, the temperature effects which followed were in the same phase but about twice as large as usual. A crucial test is given wherein correlation coefficients are computed for the march of temperatures for 16 days *after* and for 16 days *before* observed solar changes, as between rising and falling sequences of solar variation. The correlation values are respectively: After, -54.3 ± 4.9 percent; before, $+11.1\pm6.0$ percent. The first is 11 times its probable error and therefore significant, the second less than twice its probable error and hence meaningless.

From these studies it appears that day-to-day changes averaging 0.7 percent in solar radiation are presumably real and competent to produce major changes of 10° to 25° F. in temperature in the temperate zone. Such changes may be conventionally represented by the repetition 18 times per year of the day-to-day sequence, 3, 6, 9, 12, 14, 12, 9, 6, 3 thousandths calorie in solar radiation.

The author demonstrates that correlation of day-to-day solar constant values from different observatories, as relied on by critics, is incompetent to refute the sun's important variability. For the author computes correlation coefficients for 110 days as between the best stations, Montezuma and St. Katherine, obtaining 6 ± 6 percent. He then loads the values of each station simultaneously with five humps of sequences such as just numerically specified. The two stations are then certainly correlated, and carry assumed solar changes adequate to produce from 10° to 25° F. in temperature departures. The correlation coefficient now becomes 18 ± 6 percent, an increase of 12 percent, far below what critics require as being evidential.

The author points out that multiplication of values, as in monthly means or in large groupings governed by magnitudes, may sufficiently reduce accidental errors to give trustworthy evidences of solar variation, and cites numerous cases of this sort not referred to by critics.

The author mentions various considerations constantly in his mind but overlooked by critics. He discusses the procedures used in holding the solar constant values to a fixed scale for long-range comparisons.

The author points out that critics' disparagement of solar variation by the tabular use of standard deviations proves nothing and is merely reasoning in a circle, since the increase of standard deviations may quite as well be caused by real increase in solar variation as by increase of experimental error. Similarly, increase of correlation coefficients between two stations may be due to increased solar variation rather than experimental interdependence as suggested by critics, for thereby the competitive effects of accidental error are made relatively less considerable.

The author explains in detail the discovery of 12 long periods in solar variation. Critics having claimed on the basis of an equation of Brunt's, that the author's periodicities have impossibly great amplitudes, the author tabulates these periodicities completely, and then synthesizes them for the years 1920 to 1934 and compares the synthetic curve with observed monthly mean values. With a total range of 2 percent, the synthesized periodicities reproduce the original observations to within an average deviation of 0.2 percent, hence periodicities cannot have excessive amplitudes as claimed.

The author reiterates his conviction that solar variation is the principal cause of weather changes, and that with annual expenditure of $300,000 for solar observation, principal details of weather might be predicted all over the world from study of solar variation for two weeks in advance.

Since the publication of Abbot's reply the variations of solar radiation have been discussed from the standpoint of terrestrial magnetism by F. E. Dixon (Quart. Journ. Roy. Met. Soc., July 1939) who finds:

> There is evidence of a connection between changes of magnetic activity and the regular rises and falls in the solar constant noted by Abbot. The changes are appreciable only on the first two days after alterations of the solar constant commence, *and, hence, continue only as the solar constant is changing.*

Dixon found in studying the averages for magnetic character figures for each month of the year, over a period of 12 years, that opposite changes of terrestrial magnetism occur, according as the solar constant begins to rise or to fall according to Smithsonian observations.

PUBLICATION

With N. M. McCandlish, the Director prepared a paper on "The Weekly Period in Washington Precipitation."[1] A discussion of the daily precipitation at Washington, 1924 to 1939, indicates a periodicity of 6 days 18 hours, or approximately one-fourth the period of the sun's rotation. The period is such that the day of maximum precipitation in the monthly averages comes one day of the week earlier on each successive month. Unexpected changes of phase by

[1] Published shortly after the close of the fiscal year as Smithsonian Misc. Coll., vol. 98, No. 21.

one or two days occasionally occur. But the data were resolved into 15 series, averaging about 1 year in length each, when in each series from 2.5 to 8.5 times as much precipitation fell on the day of maximum as on the day of minimum expected precipitation.

NEW FIELD STATIONS

After a reconnaissance throughout southwestern New Mexico, A. F. Moore located a new solar-observing station on Burro Mountain, near Tyrone, N. Mex., approximately long. 108°33′, lat. 32°40′, alt. 8,000 ft. This station was made readily accessible to motor cars through the valued cooperation of the United States Forest Service. Water was developed about 2 miles down the road, and tanks are kept filled at the summit for gravity circulation. Telephone communication has also been established.

The observatory structures, comprising a tunnel and piers for instruments, bungalows for the observers' families, garages, and water tanks were built to specifications of Mr. Moore by Jack Heather, of Lordsburg.

The observing instruments formerly at Mount St. Katherine, and before that at Mount Brukkaros, were installed at the new Tyrone Station. Observations of the solar constant were begun there in January 1939.

As in old Mexico, the precipitation in southwestern New Mexico is almost altogether in the months July to September in normal years, and at Lordsburg averages only about 9 inches per year. We, therefore, hoped this new station would serve in a valuable supplementary way with our stations in California and Chile, where the months December to February are the worst, for continuous daily records. The past winter proved exceptional, as there was a snowfall on Burro Mountain of 72 inches. No such great fall of snow, we are informed, has occurred there for 20 years before.

OTHER FIELD STATIONS

Solar-constant observing has been continued at Table Mountain, Calif., and Montezuma, Chile, as in previous years, on every favorable day. Usually about 75 to 80 percent of the days of the year are cloudless enough for observations to be made at these stations. Exceptionally deep snow fell on Table Mountain in this past winter, amounting to over 11 feet in all.

At John A. Roebling's suggestion, all three observing stations have been equipped with excellent concrete tennis courts, constructed with grants of funds by Mr. Roebling.

STELLAR ENERGY SPECTRA

As noted in last year's report, W. H. Hoover set up apparatus in the 100-inch telescope building on Mount Wilson for measuring the distribution of energy in the spectra of the brighter stars. He observed on August 31 and on September 21 with considerable success.

The apparatus comprised 10 Christiansen filters adapted to select narrow regions of spectra ranging from 0.345μ in the ultraviolet to 1.030μ in the infrared. It was particularly suitable for observing the spectra of the blue and white stars which could not be well observed with the arrangements used by Abbot in 1923 and 1928. Hoover employed a thermoelectric element made by L. B. Clark of this Institution in connection with a highly sensitive reflecting galvanometer made by Hoover himself to observe the heat in the spectral regions selected by the filters. He calibrated the apparatus by observing the solar spectrum, whose distribution is known with considerable accuracy.

Owing to disturbances arising in the thermoelectric circuit, it was impossible to use the galvanometer at more than one-third its available sensitiveness. Yet Hoover read deflections as great as 20 millimeters in the spectrum of Vega.

Measurements were made in the spectra of five stars α Aurigae, α Cygni, α Persei, α Aquilae, and α Lyrae, all but one of which agreed very closely with those obtained for the same stars by Abbot in 1928, except that Hoover's measurements extended to much shorter wave lengths than could be reached by Abbot. However, the results are still only provisional, and intended mainly to test whether the method can be used with advantage when, about the year 1941, the 200-inch telescope becomes available.

Our conclusion is very favorable. It is believed that the disturbances encountered in the thermoelectric circuit can be minimized; that the full sensitiveness of the galvanometer can then be used; that a diffraction grating can be ruled to throw 60 percent of the incident light into one spectrum, and can be used with a simple optical system to be more saving of light than the filters; that automatic photographic registration will be practicable; and, in short, that continuous automatically recorded stellar spectrum energy curves, probably at least 10 centimeters high at maximum, can be obtained for the brightest stars when the 200-inch telescope becomes available.

PERSONNEL

Harlan H. Zodtner resigned from the service on October 31, 1938.

Hugh B. Freeman, formerly with us, was retransferred to the work from the National Advisory Committee for Aeronautics on August 1,

1938, succeeding Zodtner at Table Mountain. James H. Baden was employed as bolometric assistant on January 16, 1939. He reported at Montezuma in March 1939, vice Stanley C. Warner, who was transferred to Table Mountain after some weeks in Washington. Freeman relieved C. P. Butler at Montezuma in July 1939. Miss Nancy M. McCandlish was employed as special assistant to the Director under grant from John A. Roebling, beginning February 16, 1939.

Respectfully submitted.

C. G. ABBOT, *Director.*

The SECRETARY,
Smithsonian Institution.

APPENDIX 9

REPORT ON THE DIVISION OF RADIATION AND ORGANISMS

SIR: I have the honor to submit the following report on the activities of the Division of Radiation and Organisms during the year ended June 30, 1939:

On May 1, 1929, the Division of Radiation and Organisms was organized for the purpose of undertaking "those investigations of, or directly related to, living organisms wherein radiation enters as an important factor." This year marked the tenth anniversary of the Division. During these 10 years the Division has grown in its physical equipment and its personnel. Much of its research has been distinctly fundamental in nature, and the counsel of its members is being sought constantly on technical and research problems in the field of radiation as related to living organisms. Throughout this period most important financial aid has been given by the Research Corporation of New York.

During the past year the activities of the Division have been focused largely on problems dealing directly or indirectly with photosynthesis, factors influencing plant growth, and the stimulative action of ultraviolet radiation.

PHOTOSYNTHESIS

Work is being continued on the mechanics of photosynthesis. Experimental evidence has been obtained by Dr. McAlister which indicates the formation, during the process of photosynthesis and not before, of a material in relatively large quantities which combines with or absorbs carbon dioxide. The experimental evidence indicating the existence of this carbon dioxide-combining "intermediate" is the flow of a relatively large amount of carbon dioxide into the leaf after the light reaction is stopped, i. e., in darkness immediately following a high rate of photosynthesis. This "pick-up" is of an order of magnitude greater than any possible plant uptake due to solubility or other strictly physical processes. It occurs far too fast to be due to the action of a "buffer solution." Hence it appears to be due to a compound or "intermediate" that operates in the process of photosynthesis. That it is chlorophyllous in nature is suggested by the fact that the largest pick-up so far obtained is of the order of the

amount of chlorophyll present—molecule for molecule. That this "intermediate" is probably not free chlorophyll is suggested by experiments wherein the plant was subjected to high light in the absence of carbon dioxide for some time, and then carbon dioxide was suddenly admitted. No pick-up was here observed. Since no photosynthesis occurred in this treatment and no pick-up occurred, it is inferred that the "intermediate" is not formed under these conditions, but is formed during active photosynthesis and makes itself evident by a quick pick-up of carbon dioxide after a previous high rate of photosynthesis.

The apparatus used in these experiments was satisfactory for determining carbon dioxide concentrations below one-half percent. Dr. McAlister is reconstructing this equipment so that it will be suitable for experiments involving concentrations of carbon dioxide as high as 5 percent. With this improvement, he plans to continue his investigation to that of observing light saturation in intermittent illumination. Results from such experiments have an important bearing on all theories of photosynthesis.

A great number of automatic records have been obtained during the past year by Dr. Johnston on the recording spectrographic carbon dioxide apparatus. As a result of this work a number of fundamental changes have been made. Dr. McAlister has redesigned and Mr. Fillmen has rebuilt the spectrograph and constructed a new lamp housing for a new infrared emitter designed and made by Mr. Clark. The accuracy of measuring the photographically recorded galvanometer deflections has been increased greatly by superimposing the print of a coordinately ruled plate on the record paper before development. This procedure eliminates the necessity of correcting for changes in size of paper resulting from development. This improvement followed a suggestion made by Mr. Brydon.

Plants respire (give off carbon dioxide) both in darkness and during the process of photosynthesis in light and thus respiration apparently diminishes the intake of carbon dioxide during photosynthesis. Since the absorption of carbon dioxide by the plant is a measure of its photosynthetic activity, it is essential in order to measure photosynthesis precisely to determine what, if any, direct or indirect changes in respiration take place under the influence of radiation. Is the respiration in darkness the same as it is in light? Some interesting data bearing on this moot question have been obtained both by Dr. McAlister and by Drs. Johnston and Weintraub.

CHLOROPHYLL FORMATION AND MEASUREMENT

In any extensive quantitative study of photosynthesis, the role of chlorophyll must be considered. Work already done by Dr. McAlister on the induction phase of photosynthesis provides evidence for the

view that chlorophyll participates in the process of photosynthesis as an individual molecule rather than by units of several hundred or several thousand.

The development of apparatus and method for the determination of small amounts of total chlorophyll by Dr. Johnston and Dr. Weintraub has been completed. With a 5-cm. absorption cell, the sensitivity is 0.1 microgram ($\frac{1}{10000}$ milligram) of chlorophyll. One square centimeter of leaf is sufficient for duplicate determinations which check within 2 to 3 percent.

The method is based on the transmission of light in the region of the red absorption band of a solution of chlorophyll in acetone. The transmitted energy is determined by means of a galvanometer and a vacuum thermocouple of extremely high sensitivity that was designed and constructed by Mr. Clark. The percentage transmission of the acetone extracts of plant material is then compared with a calibration curve constructed from data obtained with solutions of purified chlorophyll.

This method eliminates the constant use of standard chlorophyll solutions and is not influenced by the presence of carotenoid pigments in the extract. Furthermore, it is unaffected by minor fluctuations in the light intensity, and errors involved in subjective intensity and color comparisons are avoided.

Experiments are in progress to determine the rate of chlorophyll formation as influenced by age and condition of plant material, temperature, and nutritional environment of the plant, the carbon dioxide content of the atmosphere, and the role played by light intensity and wave-length distribution. The relationship between rate of chlorophyll formation and intensity of light appears to be represented by a typical Blackman curve. In other words, in white light, the rate of formation during the first few hours of illumination is substantially independent of intensity above 3 to 4 ergs/mm.^{2}/sec.

Our new method of chlorophyll determination at present is limited to the estimation of total chlorophyll. It is very desirable to determine the components, *a* and *b*, separately. Plans for modifying the method with this end in view are now being formulated.

PLANT GROWTH INVESTIGATIONS

GROWTH UNDER ARTIFICIAL ILLUMINATION

Further progress has been made by Dr. Johnston in his investigations of suitable artificial illumination for the growth of plants under controlled conditions. This year work has been done with two sizes of fluorescent daylight lamps. Under the experimental conditions used for the culture of tomato plants, it was found that the intensity

was somewhat too low for good growth. However, Dr. Meier found the growth of algae to be better under these lamps than in daylight. The algae were illuminated for 12 hours daily at intensities of 150 to 300 foot-candles. The temperature during the illumination periods was 24° C., and during the dark periods, 22° C.

INFLUENCE OF LIGHT IN EARLY GROWTH OF OAT SEEDLINGS

The oat seed on germination develops roots and a shoot. The latter consists of the first internode and of a sheathing structure, the coleoptile, in which the young leaves are enclosed. Elongation of the internode proceeds rapidly in darkness but is inhibited by light. This organ has the function of raising the coleoptile with the embryonic shoot through the soil and into the air where it may develop normally. Thus in deeply planted seeds the internode receives little or no light and therefore elongates until it approaches the soil surface when its growth ceases.

Earlier studies by Dr. Johnston on the relation of light to internode development are being continued by Dr. Weintraub along the following lines:

1. Relation between amount and rate of growth of first internode and intensity of continuous illumination in various portions of the visible spectrum. Preliminary results indicate that intensity of red light (6500 A.) necessary to produce a distinct inhibition is exceedingly low—of the order of 0.0000001 erg/mm.^{2}/sec., whereas the sensitivity appears to be considerably less at other wave lengths thus far studied.

2. Influence of short periods of illumination on development of internodes in seedlings grown subsequently in darkness. The great sensitivity to light is shown by preliminary experiments in which marked or complete inhibition of growth is caused by a minute or less of low intensity (1 foot-candle) illumination.

3. Influence of alternating light and dark periods. The precise effect of light has been found to depend upon the age (developmental stage) of the seedling and upon its previous history. Changes from dark to light, or the reverse, are accompanied by marked after-effects of the preceding treatment.

4. Interrelationships between growth of first internode, coleoptile, and first leaf as influenced by light and by temperature. Evidence of such relationships has been obtained, and further studies are being made in an attempt to determine the cause and effect in them.

5. Mechanism of the response. Attempts to explain the observed behavior in terms of growth-hormone content of the plants await the development of suitable methods for the determination of the hormones. Study of such methods is in progress.

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CULTIVATION OF EXCISED PLANT ORGANS

Excised plant organs grown in culture offer very promising material for many kinds of physiological problems. The growth of excised roots of white moonflower has been found to be very markedly enhanced by illumination. These roots cultured in light also develop chlorophyll, and it has been found that they are capable of synthesizing vitamin C in light but not in darkness. This study, undertaken by Dr. Weintraub in collaboration with Dr. M. E. Reid, of the National Institute of Health, suggests that the vitamin C customarily found in the colorless roots of intact plants is synthesized in the shoots and thence transported to the roots. It is intended to continue the study with excised roots incapable of synthesizing chlorophyll.

A study of the growth of excised leaves has also been initiated and investigation of the influence of a number of growth factors is under way.

PLANT HORMONES

The assay method for growth-promoting substances, to which reference was made in last year's report, has been published. The next step in this project, which is being carried on by Dr. Weintraub, namely, the development of a quantitative technique for the isolation of the hormones from the plant, has been undertaken, but is not yet completed. With the use of these methods it is hoped to examine the occurrence of the hormones in the plant as correlated with the growth and curvature under the influence of light of various intensities and wave lengths. In connection with the study of the growth-substance extraction, some experiments have been made to ascertain the identity of the naturally occurring hormone in the oat plant. From the results thus far obtained, it appears that the conclusion of other workers that the native hormone is auxin *a*, is not necessarily valid.

The volume of detailed work necessarily connected with these plant growth studies could not have been done in the time these studies have been in progress had it not been for the able assistance of Messrs. Brydon and Zipf.

STIMULATIVE ACTION OF ULTRAVIOLET RADIATION

Dr. Meier has continued her studies on the stimulative action of ultraviolet light. In this research she has shown that a stimulative action causing increased cell multiplication of the green alga *Stichococcus bacillaris* Naeg. results from sublethal exposures to the four short wave lengths of the ultraviolet experimented with, namely, 2352, 2483, 2652, and 2967 A. The optimum stimulation point occurs

for each of these wave lengths at approximately two-thirds of the lethal exposure. The stimulative action is not transitory but has persisted in the cultures over a period of 2 years. At the end of 2 years' time, the cells in the stimulated cultures were in better condition than those in the controls. The algal cells from the stimulated cultures are slightly shorter and wider than those in the controls. The description of this research will be published under the title "Stimulative Effect of Short Wave Lengths of the Ultraviolet on the Alga *Stichococcus bacillaris* Naegeli."

A series of experiments was carried out by Dr. Meier in which both spores and amoebae of the slime mold *Polysphondylium violacea* were irradiated separately with wave length 2652 A (lethal to green algae in 60-second exposure). Since normal plants resulted from all the different exposures varying from 30 seconds to 1 hour at an intensity of 2,000 ergs/cm.^{2}/sec., experimentation with this slime mold was discontinued. It seems possible that the ultraviolet radiation does not penetrate either the amoebae or the spores.

EQUIPMENT AND MATERIALS

Several important pieces of apparatus have been developed in our laboratory and shop. The facilities available for constructing specially devised apparatus during the progress of an experiment is so essential to this type of research that its importance and the services of Mr. Clark and Mr. Fillmen cannot be overemphasized. A much needed modern autoclave has been added to the physical equipment. Dr. Meier's collection of pure cultures of algae has been added to by 14 cultures of green algae from Dr. E. Kol, Szegēd, Hungary, and 7 cultures of blue-green algae from Dr. Lee Walp, Marietta, Ohio.

PERSONNEL

No changes have occurred in the status of the Division's personnel. The capable services of E. R. Brydon and O. R. Zipf have been continued by the Works Progress Administration during the year.

PAPERS PRESENTED AT MEETINGS

New facts in photosynthesis. Presented by E. D. McAlister before the Botanical Society of Washington, D. C., November 1, 1938.

New evidence of the formation of a carbon dioxide-combining intermediate during photosynthesis. Presented by E. D. McAlister before the American Society of Plant Physiologists, Richmond, Va., December 28–30, 1938.

An apparatus and method for the determination of small amounts of chlorophyll. Presented by Earl S. Johnston and Robert L. Weintraub before the Division of Biological Chemistry of the American Chemical Society, Baltimore, Md., April 3–7, 1939.

Carbon dioxide assimilation by green plants. Presented by E. D. McAlister before the American Chemical Society at the University of Delaware, Newark, Del., May 17, 1939.

PUBLICATIONS

WEINTRAUB, ROBERT L. An assay method for growth-promoting substances utilizing straight growth of the *Avena* coleoptile. Smithsonian Misc. Coll., vol. 97, No. 11, pp. 1–10, 1938.

MCALISTER, E. D. The chlorophyll-carbon dioxide ratio during photosynthesis. Journ. Gen. Physiol., vol. 22, No. 5, pp. 613–636, 1939.

REID, MARY E. and WEINTRAUB, ROBERT L. Synthesis of ascorbic acid in excised roots of the white moonflower. Science, vol. 89, No. 2321, pp. 587–588, 1939.

Respectfully submitted.

EARL S. JOHNSTON,
Assistant Director.

DR. C. G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 10

REPORT ON THE LIBRARY

SIR: I have the honor to submit the following report on the activities of the Smithsonian Library for the fiscal year ended June 30, 1939:

The various units that comprise the library have developed one by one in connection with the 90 years and more of the Smithsonian and are important factors in the work of the Institution. Although, in the main, independent reference collections, each serving primarily the group of specialists among whom it has grown up, they form together a system of libraries cooperating to one common end—that of the increase and diffusion of knowledge.

The chief unit of the system is the Smithsonian deposit in the Library of Congress. This is the great central reservoir of material from which the other libraries of the Institution draw almost daily. Next in size and usefulness are the libraries of the United States National Museum and the Bureau of American Ethnology. The others are the Smithsonian office library, the Langley aeronautical library, the libraries of the Astrophysical Observatory, Freer Gallery of Art, National Collection of Fine Arts, National Zoological Park, Radiation and Organisms, and, last but not least, the 35 sectional libraries of the National Museum.

PERSONNEL

Unfortunately, the staff lost during the year, through transfer to positions elsewhere, two of its experienced and capable members—Virginia Whitney, under library assistant, and Clyde E. Bauman, assistant messenger. The first vacancy was filled by the promotion of Ruth Blanchard, minor library assistant in the Astrophysical Observatory. She was succeeded by Dorothy E. English. Roland O. J. Caraccio was selected for assistant messenger. There was one temporary assistant—Mrs. Marie Boborykine, who earlier in the year had been for a short time among the 15 W. P. A. employees assigned to the library.

EXCHANGE OF PUBLICATIONS

In its exchange work the library had a very successful year. It received by mail 22,406 packages and by the International Exchange Service 2,194, many of which contained more than one publication.

Among the noteworthy sendings were those from the Royal Cornwall Polytechnic Society, Falmouth; Société Forestière Mediterraneénne et Coloniale, Paris; R. Accademia Nazionale dei Lincei, Rome; Anstalt für Sudetendeutsch Heimatforschung der Deutschen Wissenschaftlichen Gesellschaft, Reichenberg; Deutsches Museum von Meisterwerken der Naturwissenschaft und Technik, München; Kongelige Frederiks Universitet, Oslo; and School of American Research, Santa Fe.

There were also important sendings of dissertations from the universities of Berlin, Bern, Bonn, Breslau, Cornell, Dresden, Erlangen, Freiburg, Gand, Giessen, Greifswald, Halle, Heidelberg, Helsingfors, Jena, Johns Hopkins, Kiel, Königsberg, Leipzig, Liege, Louvain, Lund, Marburg, München. Neuchâtel, Pennsylvania, Rostock, Tübingen, Utrecht, Warsaw, Würzburg, and Zürich, and the technical schools of Berlin, Delft, Dresden, Karlsruhe, and Zürich. These numbered, in all, 5,190, of which 2,389 were added to the Smithsonian deposit, and the rest, being medical in character and so not desired by the Library of Congress, were given to the Surgeon General's library.

As usual, the letters written by the staff related, for the most part, to the exchange work of the library. They totaled 2,290. Many of these were prepared in response to 725 want cards indicating the special needs of the libraries of the Institution. They were instrumental in arranging for 263 new exchanges and in bringing to the collections 5,757 publications that were lacking. The number thus obtained was 442 more than in 1938. It should be said, however, that some of the items in question were found, as in previous years, in the west stacks, where a mass of duplicate and other material has recently been sorted and put in order.

The library continued to solicit the return from colleges, museums, and public libraries throughout the country of duplicate copies of Smithsonian publications not wanted in their files. It is gratifying to report that the generous response to this effort—begun several years ago in cooperation with the offices of publications—has made it possible for the library to secure many volumes and parts long missing in its own sets, as well as in sets of other institutions, and to enlarge its exchange activities on behalf of its collections, particularly those in the Smithsonian deposit, the National Museum, the Astrophysical Observatory, and the National Collection of Fine Arts.

GIFTS

The past year brought a good many gifts to the library. Outstanding among them was that of 1,636 publications, mostly in Chinese, on the history, art, science, and literature of China. This collection

came from Mrs. Eugene Meyer and was a welcome addition to the library of the Freer Gallery of Art. Another important gift was a set of 40 publications on the history, life, and culture of Siam, from the Department of Fine Arts, Bangkok. Still others were 1,294 scientific journals from Dr. J. R. Swanton, 879 from Henry Otten, 85 volumes of the Engineering News and Engineering News-Record from John W. Berry, 20 or more volumes of The Osteopathic Physician from Dr. O. R. Meredith, a generous number of publications from the Public Library of the District of Columbia, 210 from the American Association of Museums, and 790 from the American Association for the Advancement of Science. There were large gifts, too, from Mrs. Charles D. Walcott and from Secretary Abbot and Assistant Secretary Wetmore, as well as many smaller ones from other members and associates of the Smithsonian staff.

The gifts also included the following: La Parasitologia en Venezuela y Los Trabajos del Dr. M. Nuñez Tovar, by Dr. Diego Carbonell, from the Honorable Eleazar López Contreras, President of Venezuela; A Catalogue of the Pictures and Drawings in the Collection of Frederick John Nettlefold, Volume IV—the concluding volume of this notable work—by C. Reginald Grundy and F. Gordon Roe, from Frederick John Nettlefold; The Zoology of the Voyage of H. M. S. *Challenger*, Part LXVIII, Report on the Seals, by Sir William Turner, from Professor James C. Brash; Prehistoria e Historia Antigua de Guatemala, by J. Antonio Villacorta C., from the author; Kokatsujiban no Kenkyu (2 copies), in 2 volumes, by Kawase Kazuma, from Yasuda Bunko; Y Mathiaid—The Mathews of Llandaff, and A List of the Birds of Australasia (2 copies), by Gregory M. Mathews, from the author; The Birds of Tropical West Africa, Volume V, by David Armitage Bannerman, from the Crown Agents for the Colonies; The Minor Elements—Their Occurrence and Function in Plant Life, with Reference Abstract Bibliography (one of 9 copies issued)—and Element Assimilation by Plant Life, with Reference Abstract Bibliography (one of 12 copies issued), by Griffith Hatton Riddle, from the Research Foundation, Inc.; Die Bambuti-Pygmäen vom Ituri, by Paul Schebesta, from M. Hayez, editor; A Guide to the Snakes of Uganda, by Capt. Charles R. S. Pitman, from the Uganda Society; An Anthology of Japanese Poems, edited and translated by Asatarō Miyamori, from the editor; The Birds of the Malay Peninsula, Volume IV—Birds of the Low Country, Jungle and Scrub (2 copies), by Herbert C. Robinson and Frederick N. Chasen, from the Federated Malay States Museums; Randers Fjords Naturhistorie, by A. C. Johansen, from Dr. Svend Dahl; The Molluscs of South Australia, Part 1, The Pelecypoda, by Bernard C. Cotton and Frank K. Godfrey, from the authors; Biological Survey of the Mount De-

sert Region, Part VI, The Insect Fauna, by William Procter, from the author; The Swedes on the Delaware, 1638–1664, by Dr. Amandus Johnson, from the author; The Book of Record of the Time Capsule, from the Westinghouse Electric and Manufacturing Company; Moss Flora of North America North of Mexico, Volume 1, Part 3, by Dr. A. J. Grout, from the author; Childe Hassan, by Adeline Adams, from The American Academy of Arts and Letters; The National Geographic Society—U. S. Army Corps Stratosphere Flight of 1935 in the Balloon "Explorer II" (6 copies, with 6 additional maps entitled "The First Photograph Ever Made Showing the Division between the Troposphere and the Stratosphere and also the Actual Curvature of the Earth, Photographed from an Elevation of 72,395 Feet, the Highest Point Ever Reached by Man")—National Geographic Society Contributed Technical Papers, Stratosphere Series, Number 2—From Maj. A. W. Stevens; Atlas der Diatomaceenkunde, Heft 1–36 (Serie I–III), by Adolf Schmidt, from Mrs. J. V. Parker, in memory of her father, Stephen S. Day; The Craft of the Japanese Sculptor (3 copies), by Langdon Warner, from the Japan Society; Scientific Results of the United States Arctic Expedition—Steamer *Polaris*—Volume 1, Physical Observations (1876), by Emil Bessels, from Emil Brach; Government and the Arts, by Grace Overmyer, from the Carnegie Corporation of New York; Atlas Geografico del Peru, by Mariano Felipe Pas Soldan, from J. G. Braecklein; Your Hall of Fame, by Robert Underwood Johnson, from the author; Poisoning the Public, by Dr. Russell C. Erb, from the author; A Collection of Books by Ephraim George Squier, edited by Frank Squier, from the editor; Mangold and Allied Families, compiled by Anna Mangold, from the compiler; A Textbook of Sterilization, by Weeden B. Underwood, from the American Sterilizer Company; The Mask of Fame, by James O'Donnell Bennett and Everett L. Millard, from Everett L. Millard; The Collection of Mary Frick Jacobs, by Dr. Henry Barton Jacobs, from the author; The Washington Directory (1822), by Judah Delano, from R. L. Polk and Company; The Lengthening Shadow of Dr. Andrew Taylor Still, by Dr. Arthur Grant Hildreth, from the author; Descendants of Edward Small of New England and the Allied Families, with Tracings of English Ancestry, revised edition in 3 volumes, by Lora A. W. Underhill, from Houghton Mifflin Company; The Modern Encyclopedia of Photography, in 2 volumes, edited by S. G. B. Stubbs, F. J. Mortimer, and G. S. Malthouse, from Frank W. Hines; The Museum and Popular Culture, by T. R. Adam, from the American Association for Adult Education; and Selected List of Bibliographies on the Polar Regions, Part 1 (2 copies), compiled and edited by the Works Progress Administration, from The Explorers Club of America.

SOME STATISTICS

The accessions to the libraries were as follows:

	Volumes	Pamphlets and charts	Total	Approximate holdings, June 30,1939
Astrophysical Observatory	80	108	188	9,679
Bureau of American Ethnology	223	----------	223	[1] 51,618
Freer Gallery of Art	1,952	108	2,060	15,437
Langley Aeronautical	33	16	49	3,443
National Collection of Fine Arts	207	220	427	6,767
National Museum	2,285	1,039	3,324	214,034
National Zoological Park	30	11	41	3,782
Radiation and Organisms	163	4	167	436
Smithsonian Deposit, Library of Congress	2,941	2,374	5,315	563,385
Smithsonian office	105	14	119	30,746
Total	8,019	3,894	[2] 11,913	[2] 899,327

[1] The holdings of the library of the Bureau of American Ethnology were reduced somewhat during the year by the elimination of material not pertinent to the work of the Bureau.

[2] From both the accessions for the year and the total holdings are omitted thousands of publications waiting to be completed, bound, or cataloged.

To the various libraries, then, the staff added 11,913 volumes, pamphlets, and charts, or 1,021 more than in 1938. They made 25,176 periodical entries and cataloged 7,298 publications—an increase respectively of 1,184 and 849 over the previous year. They prepared and filed 41,676 catalog and shelf list cards. They borrowed from the Library of Congress and other libraries 2,516 publications and loaned 11,559. They made progress with the index of Smithsonian publications and the index of exchange relations. Finally, they advanced the union catalog substantially, as follows:

Volumes cataloged	4,532
Pamphlets and charts cataloged	2,507
New serial entries made	249
Typed cards added to catalog and shelf list	7,095
Library of Congress cards added to catalog and shelf list	13,810

OTHER ACTIVITIES

There were many other activities, a few of which may be mentioned. The staff began for the National Collection of Fine Arts a card index of auction prices of works of art—a file that, when completed, will provide information for use in replying to inquiries as to the market value of such objects; sorted out the George Brown Goode papers that had been stored for years in the archives room adjoining the west stacks and turned them over to the former librarian; made special sendings of duplicates to the Marine Biological Laboratory at Woods Hole and to the following colleges and universities: Brown, Catholic, Columbia, Harvard, North Carolina, Pennsylvania, William and Mary, and Yale; selected a large number of books and serials from the surplus material in the west stacks for inclusion in the reserve collection, against the time when they will

be needed to take the place of publications now in daily use; removed the contents of the old employees' library, had the room refitted as a study, and prepared its shelves to receive part of the archives set of Smithsonian publications; returned to the Superintendent of Documents hundreds of Government publications not needed by the library; grouped a large collection of reprints and separates according to subject and distributed them among the sectional libraries; made considerable progress in reading and rearranging the shelves and revising the records in the natural history and technological libraries; examined hundreds of current serials for articles bearing on the work of the Institution and reported these articles to the curators concerned; mounted, classified, and filed more than 4,000 clippings from the Bell aeronautical collection; carried on active interlibrary loan relations with 50 libraries outside of the Smithsonian system, some of them in distant parts of the country; completed the revision of the author file of Concilium Bibliographicum cards; advanced the work of sorting the contents of the administration library and incorporating it with the main collection; and rendered even more reference and informational service than the year before, including the compiling of bibliographies for the scientists of the Institution and for others and the answering of many letters.

Two of the activities should be described in more detail. One of these was the preparation of a carefully revised and up-to-date list of the volumes and parts still needed in the serial files of the Smithsonian deposit and the library of the National Museum, especially the files essential to the work of the Institution and its branches, with a view to making a further effort—for in nearly all instances several efforts have already been made, but without success—to obtain these indispensable publications by exchange. With this objective in mind, the staff began the listing of important groups of surplus material in the west stacks. As these lists are finished, one by one, copies will be made for use in securing by special exchange arrangements, from institutions or individuals as the case may be, as many of these publications as possible. In fact, even before the year closed, the staff succeeded in obtaining through similar arrangements with certain colleges, universities, and public libraries, including Haverford, Harvard, Leland Stanford, North Carolina, Virginia, and the Free Library of Philadelphia, nearly 700 publications of value to the Institution, among them being such works as Dingler's Polytechnisches Journal, 1820–1882; The Earth and Its Inhabitants, in 26 volumes, by A. H. Keane; A History of Spanish Painting, Volumes IV to VII, Part 2, by Chandler Rathfon Post; The Haverford Symposium on Archaeology and the Bible, edited by Elihu Grant; and the Annual Review of Biochemistry, Volume VIII, edited by James Murray Luck and Carl R. Noller.

This twofold task—that of preparing both a revised list of essential publications still lacking in the main collections and a list of duplicate holdings of single items and serial runs that may be exchanged for these publications—could not have been undertaken without the aid of a number of capable employees assigned to the library by the W. P. A.

Nor without like assistance could another significant task have been achieved. That was the binding of 260 volumes for three or four of the Smithsonian collections. This work was done at the National Zoological Park, where a temporary bindery was maintained for the purpose. The result of this undertaking was most welcome—all the more so because of the serious arrearage into which the regular binding in several of the libraries has fallen.

BINDING

In fact, the library funds available for the year limited the binding to the following: for the National Museum, 400 volumes; the Bureau of American Ethnology, 2; the Astrophysical Observatory, 52; the National Collection of Fine Arts, 71; the Freer Gallery of Art, 21. The total—546 volumes—was, however, only a fraction of the number waiting to be bound.

NEEDS

A substantial increase in the annual binding allotment should, therefore, be provided, that the collections may be safeguarded from injury and loss. This is the most crying need of the library. Another need, only a little less urgent, is that of two or three more trained catalogers, with one or two expert typists to assist them. If these additions to the staff could be arranged for, the revision of the main catalogs and shelf lists and the cataloging of the sectional libraries could be rapidly advanced. As the catalog division now stands, it is far too small to undertake much more than its current work.

Respectfully submitted.

WILLIAM L. CORBIN, *Librarian.*

Dr. C. G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 11

REPORT ON PUBLICATIONS

SIR: I have the honor to submit the following report on the publications of the Smithsonian Institution and the Government branches under its administrative charge during the year ended June 30, 1939:

The Institution published during the year 27 papers in the series of Smithsonian Miscellaneous Collections, 1 annual report, and pamphlet copies of 28 articles in the report appendix, and 2 special publications.

The United States National Museum issued 1 annual report, 27 separate Proceedings papers, 1 volume (complete) of Bulletin 100, 4 bulletins, and 2 Contributions from the United States National Herbarium.

The Bureau of American Ethnology issued six bulletins.

Of the publications there were distributed 162,030 copies, which included 187 volumes and separates of the Smithsonian Contributions to Knowledge, 43,469 volumes and separates of the Smithsonian Miscellaneous Collections, 25,563 volumes and separates of the Smithsonian Annual Reports, 2,876 Smithsonian special publications, 69,658 volumes and separates of the National Museum publications, 19,527 publications of the Bureau of American Ethnology, 15 publications of the National Collection of Fine Arts (formerly the National Gallery of Art), 6 publications of the Freer Gallery of Art, 20 reports of the Harriman Alaska Expedition, 15 annals of the Astrophysical Observatory, and 694 reports of the American Historical Association.

SMITHSONIAN MISCELLANEOUS COLLECTIONS

Of the Smithsonian Miscellaneous Collections, reprints of 1 paper from volume 74 and of volume 86 were issued. There were also issued 8 papers and title page and table of contents of volume 97, and 17 papers of volume 98, making 27 papers in all, as follows:

VOLUME 74

No. 1. Smithsonian Mathematical Formulae and Tables of Elliptic Functions, First Reprint. viii+314 pp. (Publ. 2672.)

VOLUME 86

Smithsonian Meteorological Tables, Fifth Revised Edition, First Reprint. lxxxvi+282 pp. (Publ. 3116.)

VOLUME 97

No. 5. Three pictographic biographies of Sitting Bull, by M. W. Stirling. 57 pp., 46 pls. (Publ. 3482.) July 22, 1938.

No. 6. Evolution of the Annelida, Onychophora, and Arthropoda, by R. E. Snodgrass. 157 pp., 54 figs. (Publ. 3483.) August 23, 1938.

No. 7. The direct-historical approach in Pawnee archeology, by Waldo R. Wedel. 21 pp., 6 pls., 2 figs. (Publ. 3484.) October 19, 1938.

No. 8. Drawings by George Gibbs in the Far Northwest, by David I. Bushnell, Jr. 28 pp., 18 pls., 5 figs. (Publ. 3485.) December 30, 1938.

No. 9. A new nuthatch from Yunnan, by H. G. Deignan. 2 pp. (Publ. 3486.) October 10, 1938.

No. 10. Fourth contribution to nomenclature of Cambrian fossils, by Charles Elmer Resser. 43 pp. (Publ. 3487.) December 17, 1938.

No. 11. An assay method for growth-promoting substances utilizing straight growth of the *Avena* coleoptile, by Robert L. Weintraub. 10 pp., 1 pl., 1 fig. (Publ. 3488.) December 31, 1938.

No. 12. The Spence shale and its fauna, by Charles Elmer Resser. 29 pp., 6 pl. (Publ. 3490.) January 20, 1939.

Title page and table of contents. (Publ. 3529.)

VOLUME 98

No. 1. Two remarkable new species of marine shells from Florida, by Paul Bartsch. 3 pp., 1 pl. (Publ. 3524.) January 26, 1939.

No. 2. The sunspot period, by H. Helm Clayton. 18 pp., 1 pl., 12 figs. (Publ. 3526.) March 27, 1939.

No. 3. The embryology of fleas, by Edward L. Kessel. 78 pp., 12 pls. (Publ. 3527.) May 1, 1939.

No. 4. Five new races of birds from Venezuela, by Alexander Wetmore. 7 pp. (Publ. 3528.) March 10, 1939.

No. 5. Utilizing heat from the sun, by C. G. Abbot. 11 pp., 4 pls., 1 fig. (Publ. 3530.) March 30, 1939.

No. 6. Decapod and other Crustacea collected on the Presidential Cruise of 1938, by Waldo L. Schmitt. 29 pp., 3 pls., 2 figs. (Publ. 3531.) June 15, 1939.

No. 7. A new palm from Cocos Island collected on the Presidential Cruise of 1938, by O. F. Cook. 26 pp., 26 pls. (Publ. 3532.) May 29, 1939.

No. 8. Flowering plants collected on the Presidential Cruise of 1938, by Ellsworth P. Killip. 4 pp. (Publ. 3533.) May 27, 1939.

No. 9. Algae collected on the Presidential Cruise of 1938, by William Randolph Taylor. 18 pp., 2 pls., 2 figs. (Publ. 3534.) June 23, 1939.

No. 10. Mollusks collected on the Presidential Cruise of 1938, by Paul Bartsch. 12 pp., 5 pls. (Publ. 3535.) June 13, 1939.

No. 11. Echinoderms (other than Holothurians) collected on the Presidential Cruise of 1938, by Austin H. Clark, 18 pp., 5 pls. (Publ. 3536.) June 2, 1939.

No. 12. A new holothurian of the genus *Thyone* collected on the Presidential Cruise of 1938, by Elisabeth Deichmann. 7 pp., 3 figs. (Publ. 3537.) June 14, 1939.

No. 13. The polychaetous annelids collected on the Presidential Cruise of 1938, by Olga Hartman. 22 pp., 3 figs. (Publ. 3538.) June 9, 1939.

No. 14. Two new gobioid fishes collected on the Presidential Cruise of 1938, by Isaac Ginsburg. 5 pp., 2 figs. (Publ. 3539.) May 31, 1939.

No. 15. Sponges collected on the Presidential Cruise of 1938, by M. W. de Laubenfels. 7 pp., 1 fig. (Publ. 3540.) June 21, 1939.

No. 16. A new dicrocoeliid trematode collected on the Presidential Cruise of 1938, by Allen McIntosh. 2 pp., 1 fig. (Publ. 3541.) June 9, 1939.

No. 17. Polyclad worms collected on the Presidential Cruise of 1938, by Libbie H. Hyman. 9 pp., 15 figs. (Publ. 3542.) June 17, 1939.

SMITHSONIAN ANNUAL REPORTS

Report for 1937.—The complete volume of the Annual Report of the Board of Regents for 1937 was received from the Public Printer in August 1938.

Annual Report of the Board of Regents of the Smithsonian Institution showing the operations, expenditures, and condition of the Institution for the year ending June 30, 1937. xv+580 pp., 134 pls., 47 figs. (Publ. 3451.)

The appendix contained the following papers:

Constitution of the stars, by Sir Arthur Stanley Eddington.
Discoveries from solar eclipses, by S. A. Mitchell.
Changes in the length of the day, by Ernest W. Brown.
The thunderstorm, by E. A. Evans and K. B. McEachron.
The electron: Its intellectual and social significance, by Karl T. Compton.
Photography by polarized light, by J. W. McFarlane.
Measuring geologic time: Its difficulties, by A. C. Lane.
The earth's interior, its nature and composition, by Leason H. Adams.
Origin of the Great Lakes basins, by Francis P. Shepard.
The biography of an ancient American lake, by Wilmot H. Bradley.
Our water supply, by Oscar E. Meinzer.
The first crossing of Antarctica, by Lincoln Ellsworth.
Moving photomicrography, by W. N. Kazeeff.
Fresh-water fishes and West Indian zoogeography, by George S. Myers.
The breeding habits of salmon and trout, by Leonard P. Schultz.
What is entomology? by Lee A. Strong.
Maize—our heritage from the Indian, by J. H. Kempton.
The emergence of modern medicine from ancient folkways, by Walter C. Alvarez.
National and international standards for medicines, by E. Fullerton Cook.
The healing properties of allantoin and urea discovered through the use of maggots in human wounds, by William Robinson.
The aims of the Public Health Service, by Thomas Parran.
Excavations at Chanhu-daro by the American School of Indic and Iranian Studies and the Museum of Fine Arts, Boston: Season 1935–36, by Ernest Mackay.
Ras Shamra: Canaanite civilization and language, by Zellig S. Harris.
Blood-groups and race, by J. Millot.
Early Chinese cultures and their development: A new working-hypothesis, by Wolfram Eberhard.
Origin and early diffusion of the traction plow, by Carl Whiting Bishop.
Historical notes on the cotton gin, by F. L. Lewton.
The world's longest bridge span, by Clifford E. Paine.

Report for 1938.—The report of the Secretary, which included the financial report of the executive committee of the Board of Regents, and will form part of the annual report of the Board of Regents to Congress, was issued in January 1939.

Report of the Secretary of the Smithsonian Institution and financial report of the executive committee of the Board of Regents for the year ended June 30, 1938. viii+119 pp., 2 pls. (Publ. 3489.)

The report volume, containing the general appendix, was in press at the close of the year.

SPECIAL PUBLICATIONS

Explorations and field-work of the Smithsonian Institution in 1938. 116 pp., 122 pls. (Publ. 3525.) April 6, 1939.

Classified list of Smithsonian publications available for distribution June 26, 1939, by Helen Munroe. 35 pp. (Publ. 3544.) June 26, 1939.

PUBLICATIONS OF THE UNITED STATES NATIONAL MUSEUM

The editorial work of the National Museum has continued during the year under the immediate direction of the editor, Paul H. Oehser. There were issued 1 annual report, 27 separate Proceedings papers from volumes 85 and 86, 1 volume (complete) of Bulletin 100, 4 bulletins, and 2 Contributions from the United States National Herbarium, as follows:

MUSEUM REPORT

Report on the progress and condition of the United States National Museum for the year ended June 30, 1938. iii+121 pp. January 1939.

PROCEEDINGS: VOLUME 85

No. 3035. A miocene dog from Maryland, by Charles T. Berry. Pp. 159–161, fig. 68. August 10, 1938.

No. 3039. The Cuban operculate land shells of the subfamily Chondropominae, by Carlos de la Torre and Paul Bartsch. Pp. 193–403, pls. 7–39. July 27, 1938.

No. 3040. On some species of Chinese earthworms, with special reference to specimens collected in Szechwan by Dr. D. C. Graham, by G. E. Gates. Pp. 405–507. March 20, 1939.

VOLUME 86

No. 3041. Revision of the North American beetles of the staphylinid subfamily Tachyporinae—Part 2: Genus *Coproporus* Kraatz, by Richard E. Blackwelder. Pp. 1–10. October 8, 1938.

No. 3042. Descriptions of new and little-known fossil lizards from North America, by Charles W. Gilmore. Pp. 11–26, pl. 1, figs. 1–9, December 16, 1938.

No. 3043. The cambaloid milliped of the United States, including a family new to the fauna and new genera and species, by H. F. Loomis. Pp. 27–66, pl. 2, figs. 10–21. December 17, 1938.

No. 3044. Polyclads from the east coast of North America, by A. S. Pearse. Pp. 67–98, figs. 22–34. December 17, 1938.

No. 3045. Hopewellian remains near Kansas City, Missouri, by Waldo R. Wedel. Pp. 99–106, pls. 3–8. December 16, 1938.

No. 3046. The types of the polychaete worms of the families Polynoidae and Polyodontidae in the United States National Museum and the description of a new genus, by Olga Hartman. Pp. 107–134, figs. 35–41. December 7, 1938.

No. 3047. Review of the fishes of the genera *Polyipnus* and *Argyropelecus* (family Sternoptichidae), with descriptions of three new species, by Leonard P. Schultz. Pp. 135–155, figs. 42–45. December 27, 1938.

No. 3048. Revision of the beetles of the melolonthine subgenus *Phytalus* in the United States, by Lawrence W. Saylor. Pp. 157–167, pls. 9, 10. February 15, 1939.

No. 3049. New species of polychaete worms of the genus *Euphrosyne*, with notes on *Euphrosyne borealis* orsted, by Aaron L. Treadwell. Pp. 169–173, fig. 46. January 20, 1939.

No. 3050. Notes on the birds of Tennessee, by Alexander Wetmore. Pp. 175–243. January 31, 1939.

No. 3051. Annotated list of Tennessee mammals, by Remington Kellogg. Pp. 245–303. February 14, 1939.

No. 3052. Species of the foraminiferal family Camerinidae in the Tertiary and Cretaceous of Mexico, by R. Wright Barker. Pp. 305–330, pls. 11–23. May 16, 1939.

No. 3053. The cactus-feeding Phycitinae: A contribution toward a revision of the American pyralidoid moths of the family Phycitidae, by Carl Heinrich. Pp. 331–413, pls. 23–51. March 16, 1939.

No. 3054. Two new ophiurans from the Smithsonian-Hartford expedition, 1937, by Hubert Lyman Clark. Pp. 415–418, pl. 52. April 4, 1939.

No. 3055. New species of flatworms from North, Central, and South America, by Libbie H. Hyman. Pp. 419–439, figs. 47–51. April 14, 1939.

No. 3056. Echinoderms of the Smithsonian-Hartford expedition, 1937, with other West Indian records, by Austin H. Clark. Pp. 441–456, pls. 53, 54. April 5, 1939.

No. 3057. A new cave isopod from Florida, by James O. Maloney. Pp. 457–459, fig. 52. May 26, 1939.

No. 3058. Two new Atlantic species of dog sharks, with a key to the species of *Mustelus*, by Stewart Springer. Pp. 461–468, figs. 53–55. April 27, 1939.

No. 3059. A new sea star of the genus *Poraniopsis* from Japan, by Walter K. Fisher. Pp. 469–472, pls. 55, 56, fig. 56. April 4, 1939.

No. 3060. A revision of the toadfishes referred to *Porichthys* and related genera, by Carl L. Hubbs and Leonard P. Schultz. Pp. 473–496, fig. 57. April 29, 1939.

No. 3061. A new genus of starfishes from the Aleutian Islands, by Austin H. Clark. Pp. 497–500, pl. 57. May 17, 1939.

No. 3062. Eleven new species and three new genera of oceanic fishes collected by the International Fisheries Commission from the northeastern Pacific, by Wilbert McLeod Chapman. Pp. 501–542, figs. 58–70. April 28, 1939.

No. 3063. New species of moths of the families Notodontidae and Bombycidae in the United States National Museum, by William Schaus. Pp. 543–561. May 18, 1939.

No. 3064. Restriction of the genus *Gelechia* (Lepidoptera: Gelechiidae), with descriptions of new genera, by August Busck. Pp. 563–593, pls. 58–71. May 23, 1939.

BULLETINS

No. 100, volume 6 (completed). Papers on Philippine diatoms, annelids, hydroids, echinoids, and mollusks. viii+567 pp., 120 pls., 47 figs.

Title page, table of contents, and index, volume 6, Bulletin 100. Pp. i–viii, 535–567.

No. 170. Life histories of North American birds of prey (pt. 2): Orders Falconiformes and Strigiformes, by Arthur C. Bent. viii+482 pp., 92 pls. August 8, 1938.

No. 172. Birds from Siam and the Malay Peninsula in the United States National Museum collected by Drs. Hugh M. Smith and William L. Abbott, by J. H. Riley. iv+581 pp. December 3, 1938.

No. 173. Catalog of the mechanical collections of the Division of Engineering, United States National Museum, by Frank A. Taylor. viii+203 pp., 37 pls. March 2, 1939.

No. 174. Life histories of North American woodpeckers: Order Piciformes, by Arthur C. Bent. viii+334 pp., 39 pls. May 23, 1939.

CONTRIBUTIONS FROM THE U. S. NATIONAL HERBARIUM: VOLUME 26

Part 9. A revision of *Besleria*, by C. V. Morton. Pp. i–ix, 395–474. May 9, 1939.

Part 10. The Andean species of *Pilea*, by Ellsworth P. Killip. Pp. i–viii, 475–530, pls. 30–40. June 14, 1939.

PUBLICATIONS OF THE BUREAU OF AMERICAN ETHNOLOGY

The editorial work of the Bureau has continued under the immediate direction of the editor, Stanley Searles. During the year six bulletins were issued as follows:

Bulletin 118. An archaeological survey of the Norris Basin in eastern Tennessee, by William S. Webb. 398 pp., 152 pls., 79 figs., 2 maps.

Bulletin 119. Anthropological Papers, Nos. 1–6. No. 1, A preliminary report on archeological explorations at Macon, Ga., by A. R. Kelly. No. 2, The northern Arapaho flat pipe and the ceremony of covering the pipe, by John G. Carter. No. 3, The Caribs of Dominica, by Douglas Taylor. No. 4, What happened to Green Bear who was blessed with a sacred pack, by Truman Michelson. No. 5, Lemhi Shoshoni physical therapy, by Julian H. Steward. No. 6, Panatübiji', an Owens Valley Paiute, by Julian H. Steward. 204 pp., 18 pls., 37 figs.

Bulletin 120. Basin-plateau aboriginal sociopolitical groups, by Julian H. Steward. 346 pp., 3 pls., 13 figs.

Bulletin 121. Archeological remains in the Whitewater District, eastern Arizona. Part 1, House types, by Frank H. H. Roberts, Jr. 276 pp., 30 pls., 53 figs.

Bulletin 122. An archaeological survey of Wheeler Basin on the Tennessee River in northern Alabama, by William S. Webb. 214 pp., 122 pls., 25 figs.

Bulletin 123. Anthropological Papers, Nos. 7–12. No. 7, Archeological investigations in the Corozal District of British Honduras, by Thomas and Mary Gann. No. 8, Linguistic classification of Cree and Montagnais-Naskapi dialects, by Truman Michelson. No. 9, Sedelmayr's Relacion of 1746, translated and edited by Ronald L. Ives. No. 10, Notes on the Creek Indians, by J. N. B. Hewitt, edited by John R. Swanton. No. 11, The Yaruros of the Capanaparo River, Venezuela, by Vincenzo Petrullo. No. 12, Archeology of Arauquin, by Vincenzo Petrullo. 305 pp., 32 pls., 27 figs.

REPORT OF THE AMERICAN HISTORICAL ASSOCIATION

The annual reports of the American Historical Association are transmitted by the Association to the Secretary of the Smithsonian Institution and are communicated by him to Congress, as provided by the act of incorporation of the Association.

The report for 1934 (Writings on American History) and the report for 1937, volume 1 (Proceedings) were issued during the year. The report for 1935, volume 2 (Writings on American History) was in press at the close of the year.

REPORT OF THE NATIONAL SOCIETY, DAUGHTERS OF THE AMERICAN REVOLUTION

The manuscript of the Forty-first Annual Report of the National Society, Daughters of the American Revolution, was transmitted to Congress, in accordance with law, December 5, 1938.

ALLOTMENTS FOR PRINTING

The Congressional allotments for the printing of the Smithsonian Annual Reports to Congress and the various publications of the Government bureaus under the administration of the Institution were virtually used up at the close of the year. The appropriation for the coming year ending June 30, 1940, totals $73,000, allotted as follows:

Smithsonian Institution	$15,000
National Museum	34,350
Bureau of American Ethnology	13,650
National Collection of Fine Arts	400
International Exchanges	100
National Zoological Park	100
Astrophysical Observatory	400
American Historical Association	8,000
	72,000
Reserve	1,000
	73,000

Respectfully submitted.

W. P. True, *Editor.*

Dr. C. G. Abbot,
Secretary, Smithsonian Institution.

REPORT OF THE EXECUTIVE COMMITTEE OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION

FOR THE YEAR ENDED JUNE 30, 1939

To the Board of Regents of the Smithsonian Institution:

Your executive committee respectfully submits the following report in relation to the funds of the Smithsonian Institution, together with a statement of the appropriations by Congress for the Government bureaus in the administrative charge of the Institution.

SMITHSONIAN ENDOWMENT FUND

The original bequest of James Smithson was £104,960 8s 6d—$508,318.46. Refunds of money expended in prosecution of the claim, freights, insurance, etc., together with payment into the fund of the sum of £5,015, which had been withheld during the lifetime of Madame de la Batut, brought the fund to the amount of	$550,000.00
Since the original bequest the Instution has received gifts from various sources chiefly in the years prior to 1893, the income from which may be used for the general work of the Institution. To these gifts has been added capital from savings on income, gain from sale of securities, etc., bringing the total endowment for general purposes to the amount of	1,172,937.49

The Institution holds also a number of endowment gifts, the income of each being restricted to specific use. These are invested and stand on the books of the Institution as follows:

Abbott, William L., fund, bequest to the Institution	$105,889.85
Arthur, James, fund, income for investigations and study of sun and lecture on the sun	39,763.75
Bacon, Virginia Purdy, fund, for a traveling scholarship to investigate fauna of countries other than the United States	49,813.20
Baird, Lucy H., fund, for creating a memorial to Secretary Baird	15,054.53
Barstow, Frederic D., fund, for purchase of animals for the Zoological Park	756.30
Canfield Collection fund, for increase and care of the Canfield collection of minerals	38,027.52
Casey, Thomas L., fund, for maintenance of the Casey collection and promotion of researches relating to Coleoptera	7,683.94
Chamberlain, Francis Lea, fund, for increase and promotion of Isaac Lea collection of gems and mollusks	27,998.83
Hillyer, Virgil, fund, for increase and care of Virgil Hillyer collection of lighting objects	6,534.50
Hitchcock, Dr. Albert S., Library fund, for care of Hitchcock Agrostological Library	1,262.42
Hodgkins fund, specific, for increase and diffusion of more exact knowledge in regard to nature and properties of atmospheric air	100,000.00

Special research fund, gift, in form of real estate	$20,946.00
Hughes, Bruce, fund, to found Hughes alcove	15,063.10
Myer, Catherine Walden, fund, for purchase of first-class works of art for the use of, and benefit of, the National Gallery of Art	18,847.21
Pell, Cornelia Livingston, fund, for maintenance of Alfred Duane Pell collection	2,399.69
Poore, Lucy T. and George W., fund, for general use of the Institution when principal amounts to the sum of $250,000	74,127.59
Reid, Addison T., fund, for founding chair in biology in memory of Asher Tunis	29,006.83
Roebling fund, for care, improvement, and increase of Roebling collection of minerals	119,989.51
Rollins, Miriam and William, fund, for investigations in physics and chemistry	96,655.61
Springer, Frank, fund, for care, etc., of Springer collection and library	17,829.89
Walcott, Charles D., and Mary Vaux, research fund, for development of geological and paleontological studies and publishing results thereof	11,110.49
Younger, Helen Walcott, fund, held in trust	50,112.50
Zerbee, Frances Brincklé, fund, for endowment of aquaria	756.69
Total endowment for specific purposes other than Freer endowment	849,629.95

The capital funds of the Institution, except the Freer Funds, are invested as follows:

Fund	United States Treasury	Consolidated fund	Separate fund	Total
Abbott, W. L.		$72,582.18	$33,307.67	$105,889.85
Arthur, James		39,763.75		39,763.75
Bacon, Virginia Purdy		49,813.20		49,813.20
Baird, Lucy H.		15,054.53		15,054.53
Barstow, Frederic D.		756.30		756.30
Canfield Collection		38,027.52		38,027.52
Casey, Thomas Lincoln		7,683.94		7,683.94
Chamberlain		27,998.83		27,998.83
Hillyer, Virgil		6,534.50		6,534.50
Hitchcock, Library		1,262.42		1,262.42
Hodgkins, specific	$100,000			100,000.00
Hughes, Bruce		15,063.10		15,063.10
Myer, Catherine W.		18,847.21		18,847.21
Pell, Cornelia Livingston		2,399.69		2,399.69
Poore, Lucy T., and George W.	26,670	47,457.59		74,127.59
Reid, Addison T.	11,000	13,506.83	4,500.00	29,006.83
Roebling collection		119,989.51		119,989.51
Rollins, Miriam and William		87,155.61	9,500.00	96,655.61
Smithsonian Unrestricted:				
Special			1,400.00	1,400.00
Avery	14,000	37,022.91		51,022.91
Endowment		233,963.65		233,963.65
Habel	500			500.00
Hachenberg		3,998.41		3,998.41
Hamilton	2,500	401.36		2,901.36
Henry		1,202.47		1,202.47
Hodgkins (general)	116,000	30,049.51		146,049.51
Parent	727,640	1,213.76		728,853.76
Rhees	590	470.35		1,060.35
Sanford	1,100	885.07		1,985.07
Special research			20,946.00	20,946.00
Springer		17,829.89		17,829.89
Walcott, Charles D., and Mary Vaux		11,110.49		11,110.49
Younger, Helen Walcott			50,112.50	50,112.50
Zerbee, Frances Brincklé		756.69		756.69
Total	1,000,000	902,801.27	119,766.17	2,022,567.44

CONSOLIDATED FUND

Statement of principal and income for the last ten years

Fiscal year	Capital	Income	Percentage
1930	$578, 292. 40	$28, 908. 87	5. 00
1931	668, 069. 02	28, 518. 07	4. 27
1932	712, 156. 86	26, 142. 21	3. 67
1933	764, 077. 67	28, 185. 11	3. 68
1934	754, 570. 84	26, 650. 32	3. 66
1935	706, 765. 68	26, 808. 86	3. 79
1936	723, 795. 46	26, 836. 61	3. 71
1937	738, 858. 54	33, 819. 43	4. 57
1938	867, 528. 50	34, 679. 64	4. 00
1939	902, 801. 27	30, 710. 53	3. 40

FREER GALLERY OF ART FUND

Early in 1906, by deed of gift, Charles L. Freer, of Detroit, gave to the Institution his collection of Chinese and other oriental objects of art, as well as paintings, etchings, and other works of art by Whistler, Thayer, Dewing, and other artists. Later he also gave funds for the construction of a building to house the collection, and finally in his will, probated November 6, 1919, he provided stock and securities to the estimated value of $1,958,591.42 as an endowment fund for the operation of the gallery. From the above date to the present time these funds have been increased by stock dividends, savings of income, etc., to a total of $5,075,976.76. In view of the importance and special nature of the gift and the requirements of the testator in respect to it, all Freer funds are kept separate from the other funds of the Institution, and the accounting in respect to them is stated separately.

The invested funds of the Freer bequest are classified as follows:

Court and grounds fund	$568, 657. 02
Court and grounds maintenance fund	142, 927. 75
Curator fund	578, 682. 13
Residuary legacy	3, 785, 709. 86
Total	5, 075, 976. 76

SUMMARY

Invested endowment for general purposes	$1, 172, 937. 49
Invested endowment for specific purposes other than Freer endowment	849, 629. 95
Total invested endowment other than Freer endowment	2, 022, 567. 44
Freer invested endowment for specific purposes	5, 075, 976. 76
Total invested endowment for all purposes	7, 098, 544. 20

CLASSIFICATION OF INVESTMENTS

Deposited in the U. S. Treasury at 6 percent per annum, as authorized in the United States Revised Statutes, sec. 5591		$1,000,000.00
Investments other than Freer endowment (cost or market value at date acquired):		
Bonds (25 different groups)	$371,929.17	
Stocks (44 different groups)	571,726.70	
Real estate and first-mortgage notes	75,053.67	
Uninvested capital	3,857.90	1,022,567.44
Total investments other than Freer endowment		2,022,567.44
Investments of Freer endowment (cost or market value at date acquired):		
Bonds (46 different groups)	$2,443,872.57	
Stocks (63 different groups)	2,626,308.41	
Real estate first-mortgage notes	9,000.00	
	5,079,180.98	
Less temporary overinvestment of capital cash	3,204.22	5,075,976.76
Total investments		7,098,544.20

CASH BALANCES, RECEIPTS, AND DISBURSEMENTS DURING THE FISCAL YEAR [1]

Cash balance on hand June 30, 1938		$566,492.69
Receipts:		
Cash income from various sources for general work of the Institution	$67,584.69	
Cash gifts and contributions expendable for special scientific objects (not to be invested)	47,670.00	
Cash gifts for special scientific work (to be invested)	4,600.58	
Cash income from endowments for specific use other than Freer endowment and from miscellaneous sources (including refund of temporary advances)	56,828.21	
Cash received as royalties from Smithsonian Scientific Series	45,451.32	
Cash capital from sale, call of securities, etc. (to be reinvested)	53,639.08	
Total receipts other than Freer endowment		275,773.88
Cash receipts from Freer endowment, income from investments, etc	$212,751.78	
Cash capital from sale, call of securities, etc. (to be reinvested)	956,585.13	
Total receipts from Freer endowment		1,169,336.91
Total		2,011,603.48

[1] This statement does not include Government appropriations under the administrative charge of the Institution.

Disbursements:

From funds for general work of the Institution:		
Buildings—care, repairs, and alterations	$4,343.47	
Furniture and fixtures	730.71	
General administration[2]	31,024.53	
Library	2,233.83	
Publications (comprising preparation, printing, and distribution)	20,954.72	
Researches and explorations	28,134.79	
		$87,422.05
From funds for specific use, other than Freer endowment:		
Investments made from gifts, from gain from sale etc., of securities, and from savings on income	35,506.31	
Other expenditures, consisting largely of research work, travel, increase and care of special collections, etc., from income of endowment funds and from cash gifts for specific use (including temporary advances	131,082.98	
Reinvestment of cash capital from sale, call of securities, etc	79,983.01	
Cost of handling securities, fee of investment counsel, and accrued interest on bonds purchased	2,008.21	
		248,580.51
From Freer endowment:		
Operating expenses of the gallery, salaries, field expenses, etc	50,919.62	
Purchase of art objects	140,288.76	
Investments made from gain from sale, etc., of securities	302,765.56	
Reinvestment of cash capital from sale, call of securities, etc	847,319.24	
Cost of handling securities, fee of investment counsel, and accrued interest on bonds purchased	21,210.00	
		1,362,503.18
Cash balance June 30, 1939		313,097.74
Total		2,011,603.48

[2] This includes salary of the Secretary and certain others.

EXPENDITURES FOR RESEARCHES IN PURE SCIENCE, PUBLICATIONS, EXPLORATIONS, CARE, INCREASE, AND STUDY OF COLLECTIONS, ETC.

Expenditures from general funds of the Institution:		
Publications	$20,954.72	
Researches and explorations	28,134.79	
		$49,089.51
Expenditures from funds devoted to specific purposes:		
Researches and explorations	86,181.71	
Care, increase, and study of special collections	$14,727.09	
Publications	1,137.55	
		$102,046.35
Total		151,135.86

The practice of depositing on time in local trust companies and banks such revenues as may be spared temporarily has been continued during the past year, and interest on these deposits has amounted to $923.62.

The Institution gratefully acknowledges gifts or bequests from the following:

Friends of Dr. Albert S. Hitchcock, for establishment and care of the Hitchcock Agrostological Library.
Research Corporation, further contributions for research in radiation.
John A. Roebling, further contributions for research in radiation.
Mrs. Mary Vaux Walcott, for purchase of certain specimens.

All payments are made by check, signed by the Secretary of the Institution on the Treasurer of the United States, and all revenues are deposited to the credit of the same account. In many instances deposits are placed in bank for convenience of collection and later are withdrawn in round amounts and deposited in the Treasury.

The foregoing report relates only to the private funds of the Institution.

The following annual appropriations were made by Congress for the Government bureaus under the administrative charge of the Smithsonian Institution for the fiscal year 1939:

General expenses (This combines under one heading the appropriations heretofore made for Salaries and Expenses, International Exchanges, American Ethnology, Astrophysical Observatory, and National Collection of Fine Arts of the Smithsonian Institution and for Maintenance and Operation of the United States National Museum.)	$343,785.00
Preservation of collections	609,380.00
Printing and binding	68,000.00
National Zoological Park	227,000.00
Total	1,248,165.00

The Second Deficiency Appropriation Act, fiscal year 1938, approved June 25, 1938, made an appropriation of $40,000 for the Smithsonian Gallery of Art Commission to carry out the provisions of Section 2 of Public Resolution 95 entitled "Joint resolution to set apart public ground for the Smithsonian Gallery of Art, and for other purposes," approved May 17, 1938.

The report of the audit of the Smithsonian private funds is printed below:

EXECUTIVE COMMITTEE, BOARD OF REGENTS,
Smithsonian Institution, Washington, D. C.

SIRS: Pursuant to agreement we have audited the accounts of the Smithsonian Institution for the fiscal year ended June 30, 1939, and certify the balance of cash on hand, including Petty Cash Fund, June 30, 1939, to be $314,997.74.

We have verified the record of receipts and disbursements maintained by the Institution and the agreement of the book balances with the bank balances.

We have examined all the securities in the custody of the Institution and in the custody of the banks and found them to agree with the book records.

We have compared the stated income of such securities with the receipts of record and found them in agreement therewith.

We have examined all vouchers covering disbursements for account of the Institution during the fiscal year ended June 30, 1939, together with the authority therefor, and have compared them with the Institution's record of expenditures and found them to agree.

We have examined and verified the accounts of the Institution with each trust fund.

We found the books of account and records well and accurately kept and the securities conveniently filed and securely cared for.

All information requested by your auditors was promptly and courteously furnished.

We certify the balance sheet, in our opinion, correctly presents the financial condition of the Institution as at June 30, 1939.

Respectfully submitted.

WILLIAM L. YEAGER & CO.,
WILLIAM L. YEAGER,
Certified Public Accountant.

AUGUST 31, 1939.

Respectfully submitted.

FREDERIC A. DELANO,
R. WALTON MOORE,
Executive Committee.

GENERAL APPENDIX

TO THE

SMITHSONIAN REPORT FOR 1939

ADVERTISEMENT

The object of the General Appendix to the Annual Report of the Smithsonian Institution is to furnish brief accounts of scientific discovery in particular directions; reports of investigations made by collaborators of the Institution; and memoirs of a general character or on special topics that are of interest or value to the numerous correspondents of the Institution.

It has been a prominent object of the Board of Regents of the Smithsonian Institution from a very early date to enrich the annual report required of them by law with memoirs illustrating the more remarkable and important developments in physical and biological discovery, as well as showing the general character of the operations of the Institution; and, during the greater part of its history, this purpose has been carried out largely by the publication of such papers as would possess an interest to all attracted by scientific progress.

In 1880, induced in part by the discontinuance of an annual summary of progress which for 30 years previously had been issued by well-known private publishing firms, the secretary had a series of abstracts prepared by competent collaborators, showing concisely the prominent features of recent scientific progress in astronomy, geology, meteorology, physics, chemistry, mineralogy, botany, zoology, and anthropology. This latter plan was continued, though not altogether satisfactorily, down to and including the year 1888.

In the report for 1889 a return was made to the earlier method of presenting a miscellaneous selection of papers (some of them original) embracing a considerable range of scientific investigation and discussion. This method has been continued in the present report for 1939.

IS THERE LIFE IN OTHER WORLDS?[1]

By H. Spencer Jones, F. R. S.

Astronomer Royal, Royal Observatory, Greenwich

[With 5 plates]

One of the results that has followed from the employment in astronomy of larger and larger telescopes is a clearer recognition of the vastness of the universe. We see our Sun as an average sort of star, eccentrically situated in a disk-shaped stellar system containing something like 100,000 million stars and of such great extent that light takes more than 100,000 years to travel from one end of it to the other. The depths of space are peopled by myriads more of such systems, not differing greatly in size and general structure, at an average distance apart of the order of 1 million light-years. With long exposures on fast plates under good conditions, the 100-inch telescope can just reveal such systems at a distance of 500 million light-years. Within a sphere of this radius there are about 100 million systems, yet there is no indication of any thinning out in the distribution at the extreme limit to which the largest telescope can reach.

IS THE EARTH UNIQUE?

The universe being on so vast a scale, the question is inevitably suggested whether life is to be found elsewhere than on our own little Earth. Is the Earth unique in the whole of creation? I think that most people would find it difficult to believe that this can be so; for there to be but one home of life in the great universe seems such a waste of creation.

What has astronomy to say on this question? Though it does not provide a definite answer, we can get some evidence that at least suggests what the probable answer should be. It is not possible to discuss the question, however, without making certain assumptions. Suppose, in the first place, we could prove that there were other worlds where conditions resembled generally those on the Earth. Life could exist, of course, on those worlds but would it be legitimate to assume that, just as life has somehow come into existence on our own Earth, it

[1] Reprinted by permission from Discovery, n. s., vol. 2, No. 10, Jan. 1939.

would also have come into existence on the other similar worlds? There are many who take the view that life on the Earth is the result of a special act of creation and that only by a similar special act of creation could life come into being on any other world. If we accept this view, no further discussion is possible. On the other hand, we may take what seems to me the more rational view, that life somehow came into existence on the Earth because conditions were favorable for it; and that if elsewhere in the universe the conditions are favorable, there life will be found either now or in the future.

COMPOSITION OF THE LIVING CELL

Suppose, in the second place, we find that there are worlds on which conditions are so different from those with which we are familiar that no form of life to be found on the Earth could exist under them. Will it be legitimate to assume that such worlds must be devoid of life? It might be supposed that the forms of life that exist on the Earth have developed, through the slow process of evolution, in adaptation to those conditions and that on another world, where conditions are entirely different, types of life bearing no resemblance to any terrestrial forms might have developed. Living cells of both plant and animal life on the Earth, though they show a diversity in structure, all consist primarily of the elements carbon, oxygen, hydrogen, and nitrogen; sulphur, phosphorus, potash, soda, lime, and other substances may be present in smaller quantities. It is conceivable that on another world the living cells might have a different composition. They might, for instance, contain silicon in place of carbon and, as a result of this difference, they might be able to exist at temperatures high enough to destroy all terrestrial forms of life. I think that such a possibility must be ruled out. The same elements, subject to the same chemical laws, are to be found throughout the universe. Moreover, there is no reason why cells of such different composition should not exist on the Earth, yet we do not find them.

"COMPLEX AND FRAGILE"

Assuming, then, that there must be a general uniformity in composition of the elementary cells, wherever life may exist, we have some justification for concluding that certain essential conditions are necessary for life of any sort to be possible. The molecular structure of all living cells is both complex and fragile. A molecule of the protein called albumen, for instance, is built up of 72 atoms of carbon, 112 atoms of hydrogen, 18 atoms of nitrogen, 12 atoms of oxygen and 1 atom of sulphur. Such complex structures are readily broken up. High temperatures are very effective in breaking up these complicated molecules. All forms of life that we know are very sensitive to heat, and the

surest way of killing any form of life is to subject it to a high temperature. We boil water of doubtful purity because germs, which may be resistant to many destructive agents, cannot long survive at the temperature of boiling water. The more complex the form of life the more susceptible it becomes to any destructive agency because, if the protoplasm of essential cells is destroyed, the proper functioning of the organism is upset and the death of other cells, and eventually of the whole organism, as a rule results.

Low temperatures are also effective in destroying life, though some forms of life can withstand extreme cold for long periods. In such cases, however, there seems to be a state of suspended animation, in which all vital processes cease until the temperature is raised. Life becomes arrested or latent; the chemical structure is uninjured but chemical change is stopped. We cannot conceive that, if such conditions prevailed on any world, life could develop. There cannot possibly be development if all vital processes are suspended. We can therefore conclude that a world where there is a very high or a very low temperature is unlikely to be the home of any sort of life.

Satisfactory conditions of temperature are not in themselves sufficient. A further essential condition would seem to be the presence of water, either in the liquid form or as vapor. It is by imbibing water containing the chemical substances on which they feed that cells grow and divide. Neither seeds nor spores will germinate in soil that is devoid of moisture, and water is an essential constituent of the tissues of both animal and vegetable life. In the absence of moisture life, when not actually destroyed, becomes latent. Most forms of life with which we are familiar are dependent for their activity upon the presence of free oxygen, though the absence of oxygen does not seem to be necessarily fatal to every form of life. Carbon dioxide is favorable for the existence of vegetable life. Many other gases are poisonous to life: ammonia, chlorine, carbon monoxide, and sulphuretted hydrogen all have a marked toxic action. Though their presence in the atmosphere of any world would not necessarily prove conclusively that there could be no life on it, it would provide some evidence against its probability.

The presence in the atmosphere of any world of water vapor, oxygen, and carbon dioxide would therefore be evidence in favor of the possibility of the existence of life; the absence of these, combined with the presence of poisonous gases, would be evidence against the possibility of its existence. The absence of any atmosphere would necessarily be conclusive proof that life could not exist.

We can at once rule out of consideration the Sun and all other stars. The temperatures of the coolest stars are so high that only the simplest compounds can exist in their outer layers. The complicated molecular

structures of living cells would inevitably be broken up at these high temperatures, so that no life could exist. Our search for the possibility of the existence of life must therefore be directed to the cooler bodies—the planets and satellites, associated as in our solar system with a parent sun. But there we come up against the difficulty that the stars are so distant that any planetary systems they may possess are far beyond the reach of our most powerful telescopes. We cannot hope to see them; still less can we hope to learn anything about their temperatures and atmospheres. All that is possible is to study in detail the planets in the solar system and then to consider what general conclusions may be drawn from this information, supplemented by general considerations.

ATMOSPHERES OF THE PLANETS

The quest is not altogether hopeless, for we can measure the temperatures of the planets by means of sensitive instruments, such as the bolometer, and we can learn something about the constitution of their atmospheres by spectroscopic examination. The planets are not self-luminous: we see a planet by means of light from the Sun that has fallen upon the planet and has been reflected or scattered back. Suppose a planet has an atmosphere: the light by which we see it started from the Sun, penetrated to a greater or less extent into the planetary atmosphere, reaching possibly, though not necessarily, the surface of the planet, and then came out again. This light will differ from the light that we receive directly from the Sun, because of the absorption of certain wave lengths in the atmosphere of the planet. By comparing the spectrum of sunlight with the spectrum of the planet's light, we may hope to identify the absorption produced by the planet's atmosphere and to be able to assign its origin. But a complicating factor is produced by the atmosphere of the Earth, through which we view both the Sun and the planet. Absorptions occur also in this atmosphere, produced by water vapor, oxygen, ozone, carbon dioxide, and other substances. We can identify in two different ways the absorptions in the spectrum of the Sun that originate in the Earth's atmosphere. If we compare the spectra of the east and west limbs of the Sun with that of the center of the disk, absorption lines originating on the Sun will be slightly displaced in the spectra of the limbs, and in opposite directions for the two limbs, with respect to the corresponding lines in the spectrum of the center of the disk; this is merely an effect due to the rotation of the Sun. Lines originating in the Earth's atmosphere will occupy the same position in all three spectra. The second method is to compare the spectra of the Sun photographed at different altitudes. The lower the altitude, the greater the length of the path of the light through

our atmosphere and the greater, therefore, the absorption produced by the atmosphere.

The spectrum of the planet may show some absorptions that are not to be found in the spectrum of the Sun, and other absorptions that are present in the spectrum of the Sun but that are known to be of terrestrial origin. The former can be attributed at once to the atmosphere of the planet; the latter may or may not be produced by the atmosphere of the planet as well as by our own atmosphere. We can endeavor to distinguish between the two possibilities by photographing the spectra of the Sun and the planet when the two bodies are at the same altitude and comparing the intensities of the absorptions. If they are stronger in the spectrum of the planet relatively to absorptions of solar origin, there must be absorption in the planetary atmosphere superposed on absorption in our atmosphere. The principle is simple but its application is not always easy.

VELOCITY OF ESCAPE

The most detailed information about the constitution of planetary atmospheres can be obtained by observations at an observatory on a mountain or high plateau. Most of the information that we possess has been derived from observations at the Mount Wilson Observatory, and at the Flagstaff Observatory, Arizona.

We can infer something, however, about the atmospheres of the planets without making any observations at all. A planet can retain an atmosphere only by virtue of its gravitational pull. If we could imagine our globe to be suddenly annihilated, leaving the atmospheric shell undisturbed, the atmosphere would rapidly dissipate into space. It is the gravitational pull of the Earth that prevents this dissipation. A rocket shot off from the Earth will be drawn back by the force of gravitation unless the velocity of projection exceeds 7 miles a second. This critical velocity is called the velocity of escape. For any other planet the velocity of escape will have a different value, the square of the velocity being proportional to the mass of the planet and inversely proportional to the radius. Because, as we shall see, this velocity is a very important criterion, the values for several bodies are tabulated:

	Miles per second
Moon	1.5
Mercury	2.2
Venus	6.5
Earth	7.0
Mars	3.1
Jupiter	38.0
Saturn	23.0
Uranus	13.0
Neptune	14.0
Sun	386.0

In every cubic inch of the air that we breathe there are some 500 million billion minute particles called molecules, flying about rapidly in all directions and continually colliding with each other. The lighter the molecule the higher is its average speed. The average speed of a molecule of hydrogen is 1¼ miles a second, whereas the average speed of a molecule of oxygen or nitrogen is not much greater than one-fourth mile a second. Consider what is happening at the top of the atmosphere; there will frequently be molecules that rebound after a collision with a speed several times as great as the average speed. Suppose hydrogen molecules are present: the speed of some of these might well exceed 7 miles a second, the velocity of escape from the Earth. If they happened to rebound in a direction away from the Earth, they will escape from the Earth's gravitational pull, unless they should happen to collide with some other molecule. A slow escape of hydrogen from the outer layers of the Earth's atmosphere would therefore be expected. The atmosphere of the Earth, in fact, contains little or no hydrogen, the reason being that it has gradually slipped away into space. For nitrogen and oxygen, on the other hand, the velocity of escape is more than 20 times greater than the average speed of the molecules. Velocities so much greater than the average will rarely be reached, so that oxygen and nitrogen are held prisoners by the invisible but powerful bonds of the Earth's gravitation.

THE ATMOSPHERE OF THE MOON

Now contrast the Moon and Jupiter with the Earth. It is rather more difficult for the Moon to hold an atmosphere of oxygen and nitrogen than it is for the Earth to hold an atmosphere of hydrogen. The Earth has existed long enough to lose its hydrogen and so we may anticipate that the Moon has lost not merely hydrogen but also oxygen, nitrogen, and water vapor and that it may be entirely devoid of atmosphere. The velocity of escape from Jupiter, on the other hand, is so high that it is impossible even for hydrogen, the lightest of all substances, to be lost. We may accordingly expect to find a very extensive atmosphere on Jupiter.

These expectations are fully confirmed by observation. The startling suddenness with which a star disappears when the Moon passes in front of it, or occults it, proves that there can be no atmosphere. If there were any atmosphere, the light from the star would be refracted through it and the star would disappear gradually. The Moon is the nearest to us of the heavenly bodies and its surface can be studied in considerable detail. We see mountain ranges; many ring-shaped mountains, both small and large; great plains; and narrow cracks or fissures in its surface. But there are no oceans, lakes or rivers; if these ever existed on the Moon, they have gradually evaporated and the

water vapor has dissipated into space. If there were a lunar inhabitant equipped with a powerful telescope, he would be able to see many signs of human activity on the Earth. No signs of the activities of lunar inhabitants are to be seen on the Moon; it is a dead world, without any atmosphere and without any water and therefore entirely devoid of life.

THE PLANETS

Jupiter.—The appearance of Jupiter is far different. We see markings in the form of bright patches and dark patches, arranged for the most part in belts parallel to the equator. At first sight, these markings might be thought to be surface features. But further examination shows that they are continually changing and that the appearance is never twice the same. All that we can see on Jupiter are cloud formations; we can never penetrate to the solid surface of the planet. Analysis by the spectroscope of the light from Jupiter reveals an atmosphere very different from our own. We can find no trace of oxygen, or of carbon dioxide, or of water vapor. The absence of water vapor is not to be wondered at, for when we measure the temperature of Jupiter we find it to be about −200° F., so that any moisture would be precipitated as ice or snow. The prominent features of the spectrum of Jupiter are strongly marked absorptions characteristic of ammonia and of marsh gas, the poisonous gas that the miner knows as fire damp.

Strange though an atmosphere containing pungent ammonia and poisonous marsh gas may seem, it is precisely the type of atmosphere that might have been predicted. Jupiter, in common with the other planets, was formed from matter ejected by the Sun. The Sun consists largely of hydrogen, and Jupiter, when it was first formed, must also have contained a large proportion of hydrogen. The great gravitational pull of Jupiter prevented this hydrogen from escaping. As Jupiter cooled, the oxygen in its atmosphere combined with some of the hydrogen to form water vapor and this, with further cooling, was deposited on the surface as a thick layer of ice. Nitrogen and carbon also combined with some of the excess hydrogen to form saturated compounds. The most volatile compounds of hydrogen with nitrogen and carbon are ammonia and marsh gas, respectively, and these are the gases that we should expect to find in the atmosphere of Jupiter. We infer also, though we cannot test it by observation, that there must be a great deal of hydrogen in the atmosphere. A poisonous atmosphere, containing neither oxygen, carbon dioxide, nor moisture, combined with an extremely low temperature, must make any form of life quite out of the question.

The other large planets, Saturn, Uranus, and Neptune, can be briefly disposed of. Being more distant from the Sun than Jupiter, their temperatures must be appreciably lower. For the planets have

no residual heat of their own. There is a balance between the heat they receive from the Sun and the heat they radiate back into space. The farther from the Sun a planet is, the less is the heat that falls on unit area of its surface; the lower, therefore, must be the average surface temperature. These three planets are all sufficiently massive to have retained their hydrogen; marsh gas is a prominent constituent of all their atmospheres, but ammonia becomes less prominent as, with an increasing degree of cold, it is frozen out of the atmosphere. The temperature of Neptune is so low that nitrogen could only exist on it in the solid state. We need not look for life on these distant frozen wastes.

Mercury.—Returning to the nearer planets, it will be noticed that the velocity of escape from Mercury is not much higher than that from the Moon. Mercury always turns the same face to the Sun, so that one hemisphere has perpetual day and the other has perpetual night. The sunlit face is intensely hot; where the Sun is overhead it is as hot as a bath of molten zinc. This high temperature would facilitate the escape of any atmosphere, because the higher the temperature the faster the molecules move. We must conclude that Mercury, in common with the Moon, is devoid of any atmosphere and is a dead, arid world. The surface of the planet shows nothing more than extremely faint markings, only observable with great difficulty; it is probably a uniform plain, with no very distinctive features.

Venus.—Venus and Mars have special interest and require more detailed consideration. Venus is the planet most nearly equal to the Earth, both in size and in weight. The velocity of escape from Venus being nearly the same as from the Earth, we expect to find an extensive atmosphere on Venus, though the hydrogen will have escaped. The telescope confirms this, for we find Venus to be covered with a dense permanent layer of clouds, which entirely obscures her surface. Faint, ill-defined markings are sometimes seen, but they have no permanence.

There has been a great development in recent years in the use of photographic plates sensitive to the infrared light, the light of long wave length to which the eye is not sensitive, for the photography of distant landscapes, because the infrared light is able to penetrate haze or fog much more easily than the light of short wave length, the blue, violet and ultraviolet light to which ordinary photographic plates are sensitive. Venus has been photographed using these infrared-sensitive, or haze-cutting plates in the hope that something of her surface might be revealed. But such plates show no more than our eyes can see. The cloud layer is too thick.

The temperature of Venus has been measured. The temperature of the sunlit face reaches 80° or 90° F., while that of the dark face falls

to about 40° below freezing point. Venus has a long day; its length is not known exactly but it is somewhere about 30 of our days. This explains the great difference between the midday and midnight temperatures on Venus. The temperatures on the surface of Venus, below the permanent layer of cloud, are likely to be appreciably higher than the measured temperatures. The temperature conditions on Venus are certainly not such as to make life impossible.

What about her atmosphere? No evidence of the presence of either oxygen or water vapor has been found. The tests for oxygen are very sensitive; those for water vapor are less sensitive, but the failure to detect the presence of water vapor is surprising because the clouds on Venus must almost certainly be clouds of water vapor, similar to the clouds in our atmosphere. The explanation is probably that the atmosphere above the cloud layer is pretty dry. There may be a very humid atmosphere below the clouds. One important fact has been established—an abundance of carbon dioxide, very greatly in excess of the amount in our own atmosphere, is present in the atmosphere of Venus.

The scarcity of oxygen, combined with the abundance of carbon dioxide, provides a clue to the conditions prevailing on Venus. On a cooling planet of the size of Venus we should expect to find both water vapor and carbon dioxide evolved from the molten rocky mass as it cooled and solidified. We should not expect to find oxygen, because oxygen is a chemically active element and does not like to exist alone. The surprising thing is not the absence of oxygen in the atmosphere of Venus, but the abundance of it in our own atmosphere. The oxygen is continually being depleted from our atmosphere by combining with other substances and there must be a source of replenishment. This is undoubtedly provided by the vegetation on the Earth's surface, which extracts carbon dioxide from the air and uses the carbon for building up the plant cells, giving out oxygen. The supply of carbon dioxide is in turn replenished by processes such as combustion, respiration, and the decay of vegetable matter. When life started on the Earth there was probably plenty of carbon dioxide but comparatively little oxygen in the atmosphere. We seem to see in Venus a world where the conditions are somewhat similar to those that the Earth passed through millions of years ago. Any life on Venus can be, at the most, primitive plant life. It is possible that life may be in process of gradual development and that in the millions of years to come, when life on the Earth may be nearing extinction, Venus may be the home of higher and higher types of life.

Mars.—The last of the planets to be considered is Mars, the most interesting of all the planets. In the telescope it appears as a beautiful orange-colored object, on which misty dark markings can be seen. These markings are permanent, and we see them carried round as the

planet rotates in a day that is some 40 minutes longer than our day. Careful observation shows that these markings undergo changes, both of form and of coloration, which are in part seasonal in character. Around whichever pole is visible there is seen a bright white cap; the two polar caps show regular seasonal changes in size, growing in the winter and shrinking in the summer. Their appearance suggests something similar to the regions of ice and snow around the poles of the Earth, though from the rate at which they melt as the summer advances it can be inferred that the Martian polar caps are not more than a few inches in thickness.

There has been much controversy over the existence of the so-called canals on Mars, a geometrical network of perfectly straight, narrow, and sharply defined lines connecting up the dark markings, which some observers claim to have seen. The American astronomer, Percival Lowell, built up a romantic theory about these canals. He regarded them as irrigation channels, carrying water to the dark regions or oases from the melting polar caps. His conclusion was that the canals were artificial structures, made by a race of intelligent Martian beings, who were engaged in a desperate struggle for existence on a semiarid planet. Lowell's geometrical network of sharply defined canals has not been confirmed, however, by the most keen-sighted observers, with the largest telescopes, observing under the most favorable conditions. It seems that they are an illusion of vision, arising from a psychological tendency for the eye, when looking at something that is almost at the limit of vision, to connect up detail by narrow lines to form a geometrical pattern. We must abandon Lowell's theory. What is certain is that we can see markings on the surface of Mars, and that these undergo seasonal changes, which seem to indicate the seasonal growth of vegetation.

PROOFS OF AN ATMOSPHERE

The low velocity of escape from Mars suggests that, if Mars has an atmosphere, it must be very tenuous. We obtain direct proof that it has an atmosphere by taking photographs in infrared and ultraviolet light. The infrared photographs show the surface markings clearly; the ultraviolet photographs do not show them at all. The scattering of the ultraviolet light by the atmosphere is enough to prevent its penetrating to the surface and out again. The images in ultraviolet light are larger than those in infrared light, and a comparison of them shows that the atmosphere has a considerable depth—not less than 50 miles. Comparison with terrestrial photographs taken under favorable conditions suggests, nevertheless, that the total atmospheric pressure on Mars does not amount to more than a few percent of that at the surface of the Earth.

Another proof of an atmosphere on Mars is the appearance of clouds. These are of two kinds. Some are shown clearly in the ultraviolet photographs and not in the infrared; such clouds must be high up in the atmosphere and sufficiently thin to allow the infrared light to pass through. Other clouds are seen in the infrared and not in the ultraviolet photographs; they must be low-lying clouds of water vapor, seen through a yellowish atmosphere.

Endeavors to detect oxygen and carbon dioxide in the atmosphere of Mars have so far been unsuccessful, and it can be concluded that the amounts of these gases in the Martian atmosphere are less than one-tenth of 1 percent of the amounts in our atmosphere. Water vapor must undoubtedly be present for, although there are no open seas on Mars, the polar caps must be caps of ice or snow. Water vapor has been detected, in fact, at the Lowell Observatory, by comparing the spectra of Mars and the Moon at the same altitude, under conditions of exceptional atmospheric dryness. The reddish color of much of the surface of Mars is probably due to the oxidation of iron-bearing ores by atmospheric oxygen and is in marked contrast to the gray unoxidized rocks on the Moon. It is probable that there is still a little, though not much, oxygen in the atmosphere.

The extreme tenuity of the Martian atmosphere is responsible for great diurnal variations of temperature; a scanty atmosphere, with very little moisture in it, does not have much blanketing effect. Near noon, in the equatorial regions, the temperature rises to about 50° F.; but in the afternoon, as the Sun gets lower, the temperature falls rapidly. After sunset the cold becomes intense and the minimum temperature at night is about 130° below zero. With such an enormous daily range of temperature, the conditions for any form of life must be very trying. Whether animal life can exist seems doubtful, though it is impossible to assert that life may not have evolved to suit those conditions. In Mars we see a world where conditions resemble those that will probably prevail on our Earth many millions of years hence, when most of our present atmosphere will have been lost. Mars appears to be a planet of spent or nearly spent life.

This brief survey of the planets in the solar system has not given any clear indication of life elsewhere than on the Earth, with the probable exception of some vegetation on Mars. It seems that Mars is a planet where life may be on the verge of becoming extinct and that Venus is a planet on which life may be on the verge of coming into existence. Elsewhere there is no life of any sort.

PLANETS IN OTHER SYSTEMS

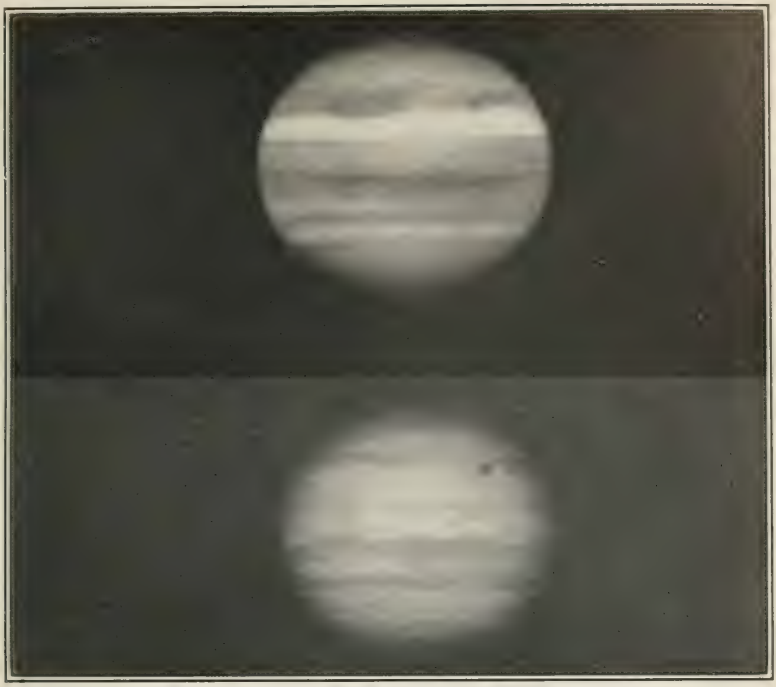
But what is the likelihood that other stars have planets associated with them and that life may exist on some of these? To assess the probability that other stars have systems of planets we must be able

to account for the origin of the solar system. This is one of the most difficult problems in astronomy, which has not yet been completely solved in a satisfactory manner. The only hypothesis which seems to account for the facts is to suppose that a few thousand million years ago another star passed close to the Sun. The passage of the star raised a great tidal protuberance on the Sun, which became greater and greater until a long jet of matter was drawn out. As the stranger star passed on its way, the tidal wave on the Sun subsided but the matter drawn out from the Sun broke up and condensed into planets. The stars are so far apart that such a close encounter of two stars can rarely happen; calculation suggests that it may occur about once in 5,000 million years. Hence planetary systems are not the rule, but very much the exception, and in our stellar universe there can be but few stars, in addition to the Sun, which have systems of planets attached to them.

In any planetary system, everything seems to be weighted against the possibility of the existence of life. If the planet is too near its parent sun, it will be too hot for life to exist; if it is too far away, it will be too cold. If it is much smaller than the Earth, it cannot retain any atmosphere. If it is much larger, it will have retained too much atmosphere, for when hydrogen cannot escape, the formation of the poisonous gases, ammonia and marsh gas, appear to be almost inevitable.

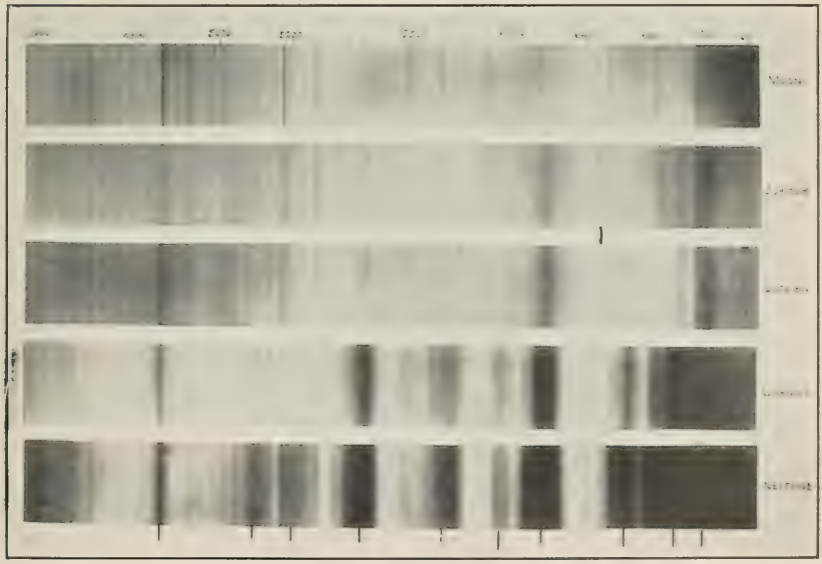
"IT SEEMS PROBABLE THAT THERE ARE OTHER WORLDS WHERE LIFE EXISTS"

Amongst the vast number of stars in any one stellar universe, we should expect to find only a limited number with a family of planets; and amongst these families of planets there cannot be more than a small proportion where conditions exist that make life possible. On the other hand we must remember the vastness of creation; there are about 100 million separate universes in the region of space accessible to observation, and we know not how many more beyond. If in each universe there are not more than two or three dozen stars with families of planets, the total number of planetary systems within the relatively small region of space that we can survey is immensely great. If the proportion of planets on which life can exist is not more than one in a million—and our survey of the solar system suggests that this is a considerable underestimate—the total number of planets where conditions are suitable for life must be considerable. So it seems probable that there are other worlds where life exists, though that life may be entirely different from any form of life with which we are familiar.



1. JUPITER, PHOTOGRAPHED IN ULTRAVIOLET LIGHT (ABOVE) AND IN INFRARED LIGHT (BELOW).

The markings shown are in each case atmospheric.

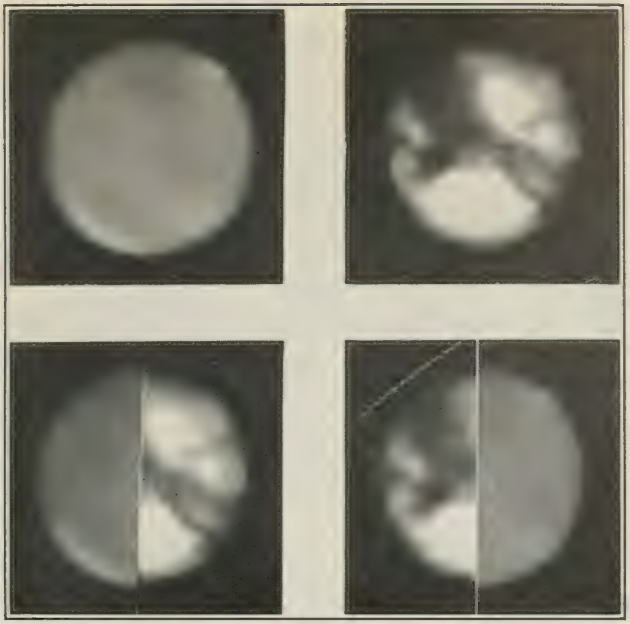


2. SPECTRA OF THE MOON, JUPITER, SATURN, URANUS, AND NEPTUNE.

The bands due to marsh gas, which become progressively stronger from Jupiter to Neptune, are marked at the bottom. The faint marked band in the spectrum of Jupiter is due to ammonia.

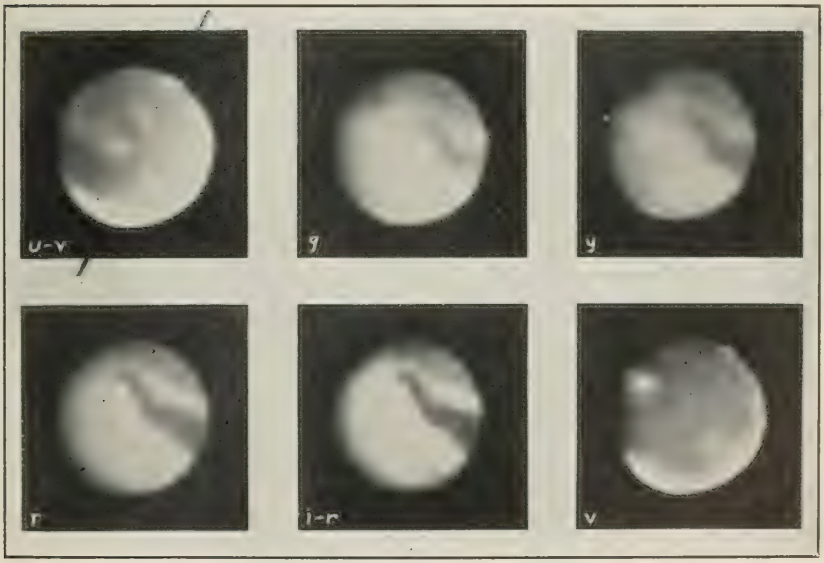


MOON, SHOWING MARE IMBRIUM.



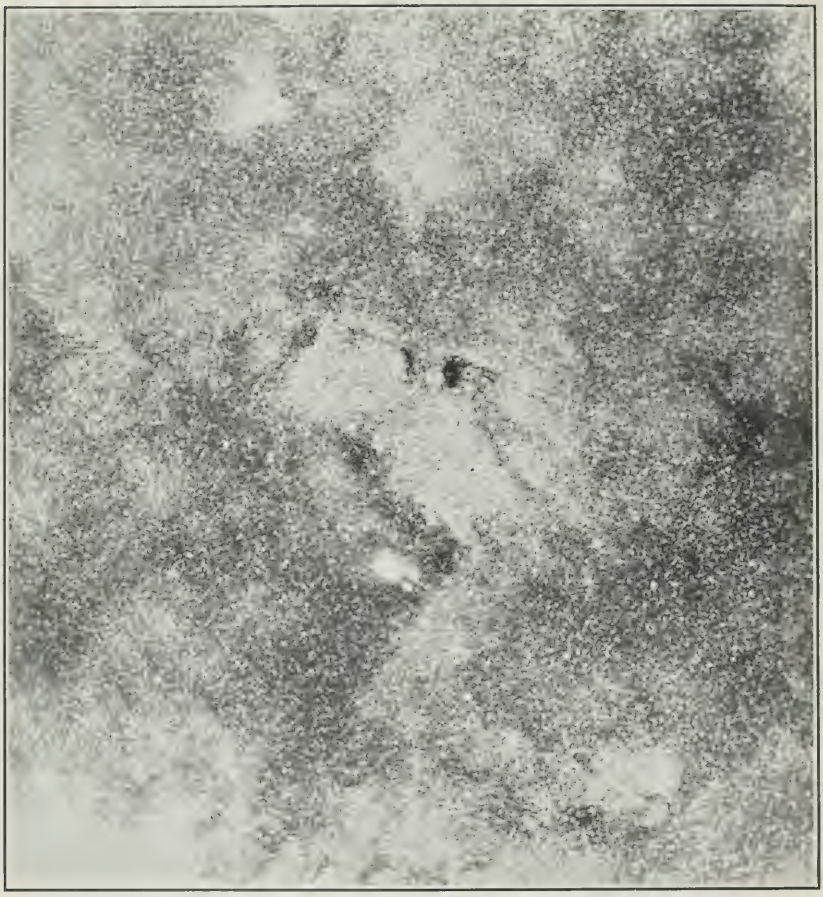
1. PHOTOGRAPHS OF MARS IN ULTRAVIOLET LIGHT, SHOWING ATMOSPHERE (LEFT), AND IN INFRARED LIGHT, SHOWING SURFACE (RIGHT).

Opposite halves are juxtaposed below, to show larger size of ultraviolet image, due to the considerable depth of atmosphere.



2. PHOTOGRAPHS OF MARS IN ULTRAVIOLET, GREEN, YELLOW (ABOVE), RED, INFRARED, AND VIOLET (BELOW).

The surface details become progressively clearer with increase in wave length of light. The rotation of the planet (the direction of the axis indicated in the first image) causes the dark markings to move across the disk. The cloud, shown faintly near the center of the disk in the first image, is beginning to form near noon; in the last image it is well shown near the limit, having become strong by late afternoon.



SMALL STAR-CLOUD IN SAGITTARIUS, SHOWING LARGE NUMBER OF STARS IN MILKY WAY REGIONS.



NEBULA IN COMA BERENICES, A STELLAR UNIVERSE SEEN EDGEWISE ON.

USE OF SOLAR ENERGY FOR HEATING WATER [1]

By F. A. Brooks

Agricultural Engineer, California Agricultural Experiment Station

[With 3 plates]

Direct use of solar energy as heat is now being made by several thousand solar water heaters in Florida, California, and the South. Successful use depends, of course, on the number and regularity of sunshine days and on the proper design of the heating system. There are two common types of solar water heaters and several methods of combining the solar heater with other water-heating systems.

Recommendations for installations and construction of solar water heaters are to be found on pages 174 to 181. Investigations and experiments in California [2] concerning water temperatures and the rates of heating water in different solar-heater systems are described on pages 161 to 174. Methods of steam generation, distilling, and cooking by solar energy in which Dr. Abbot uses aluminum reflectors to obtain high temperatures have been described in a previous publication of the Institution.[3]

AVAILABILITY OF SOLAR ENERGY

The amount of radiant energy coming from the sun is almost constant—7.15 B. t. u.[4] per square foot each minute—on a surface perpendicular to the sun's rays outside the earth's atmosphere.[5] Reflection and scattering of the sun's rays occurs in the outer atmosphere by dust and water and gas molecules. Absorption there is mainly by ozone. In the lower atmosphere reflection by clouds and absorption by the water vapor and carbon dioxide gases and by smoke and dust further diminishes the solar radiation reaching the earth's surface.

Atmospheric depletion of solar energy.—The large variation in energy received on the earth's surface on clear days at the same time

[1] Material selected from University of California College of Agriculture Bull. 602, 1936.

[2] Brooks, F. A., Solar energy and its use for heating water in California. Univ. California, Coll. Agr. Bull. 602, 64 pp., 1936.

[3] Abbot, C. G., Utilizing heat from the sun. Smithsonian Misc. Coll., vol. 98, No. 5, publ. 3530, pp. 1–11, 1939.

[4] B. t. u., or British thermal unit, which is the quantity of heat required to raise the temperature of 1 pound of water 1° F.

[5] Abbot, Charles G., The Sun. 2 ed., 433 pp. (see specifically p. 296). D. Appleton & Co., New York, 1929.

of year indicates great differences in the composition of the atmosphere and in the quantity of suspended particles of smoke and dust. Observations by Coblentz and Kahler[6] near Washington, D. C., show that the total solar energy received at sea level may vary even on clear days 25 percent (from 3.64 to 4.86 B. t. u. per square foot minute) at noontime in September. The absorptive effect of heavy smoke over large industrial areas can be judged by the simultaneous observations showing that the intensity of sunshine in Chicago may be only 55 percent of that at Madison, Wis.[7] Except during great dust storms, the depletion due to dust in the atmosphere is less obvious than that due to smoke. The usual fine atmospheric dust, when considered as including smoke, haze, and liquid particles, can be estimated as causing about 10 percent depletion[7] at midday and, of course, more as the sun approaches the horizon and the sun's rays pass more obliquely through air for a greater distance.

Solar energy received on a horizontal surface at the ground.—The regular Weather Bureau pyrheliometers measure the insolation on a horizontal surface inside an evacuated spherical glass. The readings, being based on a calibration with an uncovered master pyrheliometer, indicate the amount of solar energy received horizontally outside the instrument. Figure 1 shows the average daily record for clear weather at Fresno, Calif., in July and December, 1933. The most important seasonal variation is the number of hours of sunshine per day—nearly 15 in midsummer, but only a little more than 9 in midwinter. Another seasonal variation that greatly reduces midwinter solar energy received on a horizontal surface is the height of the sun in the sky. At Fresno this is represented by cosines of the angles of incidence of 0.97 at noon in July and of 0.50 at noon in December.

The graphic areas under the curves of figure 1 represent the total energies received on clear days. Any cloudiness would reduce the amount of energy received, and prolonged shade at noon would seriously interfere with the operation of a solar heater. The clear-day records in figure 1 show the winter energy to be 37 percent of the summer, but the total energy received during the whole month of December was only one-sixth of that received in July. These figures indicate that the average December cloudiness deprived Fresno of more than half the maximum total energy. This is a seasonal effect in the central valleys of California because cloudiness is rare in the summer.

[6] Coblentz, W. W., and Kahler, H., A new spectropyrheliometer and measurements of the component radiations from the sun. Dep. Commerce, Sci. Pap. Bur. Standards, vol. 16, Pap. 378, pp. 240–41, 1921.

[7] Kimball, H. H., The distribution of energy in the visible spectrum of sunlight, skylight, and total daylight. Int. Illuminating Congr., Pap. No. 12,[4] p. 10, 1928.

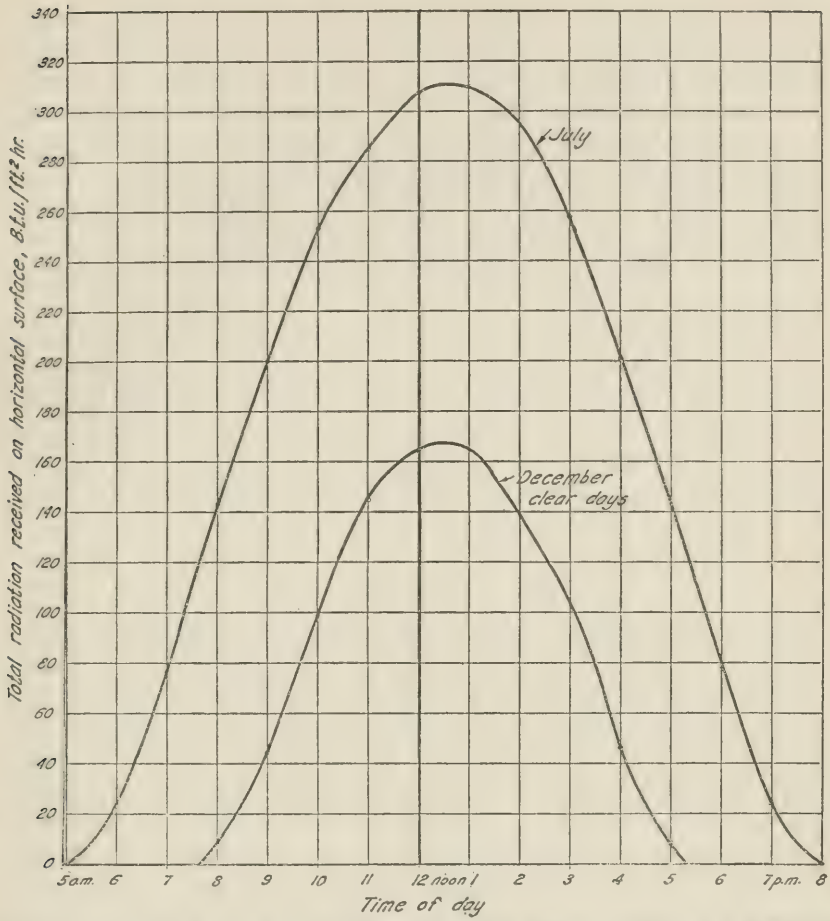


FIGURE 1.—Average hourly solar radiation (direct plus diffuse) received on a horizontal surface at Fresno, Calif., in July and on clear days in December 1933.

NUMBER OF DAYS OF SUNSHINE

Reports of the number of clear, partly cloudy, and cloudy days for a large number of stations in each State are published by the United States Department of Agriculture as "Climatological Data" in the United States Monthly Weather Review. A few stations give pyrheliometer measurements by the week, and several stations report the percentages of possible sunshine, but for a general understanding one must use the rough cloudiness reports. By definition [8] "partly cloudy" indicates sunshine, on the average, for about half the day. In estimating, therefore, the total number of days of available sun-

[8] "Clear" means that the sun is obscured for from 0 to 0.3 of the day; "partly cloudy" for from 0.4 to 0.7; and "cloudy" means that the sun is obscured for from 0.8 to the whole day.

shine, one may reasonably include half the number of "partly cloudy" days with the number of "clear" days. This arbitrary interpretation of the reports for 10 years shows a consistent distribution of sunshine throughout California. Large variations occur annually and there are pronounced local differences. The effect of a low coastal range is seen in the 10-year average of 204 sunshine days per year near the ocean at Santa Ana compared with 310 at Corona 20 miles inland. Another striking contrast is from 215 sunshine days annually at San Francisco to 302 days at Alvarado only 23 miles away across the lower bay.

Where there is much more cloudiness during the winter than at other times of the year, it can be expected that solar heaters will be used only during the warmer seasons. In these cases the study of number of sunshine days is better restricted to the normal growing season from the average latest spring frost to the average earliest fall frost. In California the major agricultural areas have the equivalent of 7 months or more of sunshine between frosts.

ABSORPTION OF SOLAR ENERGY

The absorption and emission of radiant energy depends upon the temperature and surface characteristics of the body in question, the relation of the surface to its surroundings, and the temperature and radiation characteristics of the surroundings. The temperature of the sun's surface (more than 11,000° F.)[9] is so great that the predominant radiation is in short wave lengths largely in the visible region. Radiation from substances at terrestrial temperatures is relatively in long wave lengths, the peak being at about 10 microns. In general the absorptivity for solar radiation varies roughly as the visual darkness of the surface—any brightness indicating some reflection and consequently a deficiency in absorption or transmission of the visual short-wave radiation. Long-wave emissivity or absorptivity cannot be judged visually. Common building materials, paints, and roofs (except asbestos and metals) have nearly perfect emitting surfaces for long-wave radiation.

Long-wave radiation from the atmosphere is in strong spectral bands in accordance with the radiation characteristics of water vapor, carbon dioxide, and ozone. The rate of incoming atmospheric radiation varies with moisture content and follows strongly the temperature variation of the air near the ground. In general the net exchange of long-wave radiation between the earth and the sky is outgoing—to balance the incoming short-wave insolation. At night during the winter radiation frosts in Riverside, Calif., the net radiation loss rarely exceeds 0.5 B. t. u. per square foot per minute for a black body.

[9] Abbot, Charles G., The Sun. 2d ed., 433 pp. (see specifically p. 116). D. Appleton & Co., New York, 1929.

A white surface out-of-doors acts partly as a one-way heat valve because it reflects most of the sunshine and yet at night readily emits ordinary heat waves to the cold sky. However, new galvanized iron, for example, has a solar absorptivity of 0.65 [10] and a long-wave emissivity of 0.23,[11] indicating high daytime heating and relatively low nocturnal cooling by radiation. Polished metals, particularly aluminum, act as radiation shields, being excellent reflectors and also poor emitters. Such properties are valuable for minimizing diurnal temperature fluctuations.

Glass is opaque to long-wave radiation and therefore acts as a solid surface in emitting ordinary heat waves. Sunshine or short-wave radiation is readily transmitted, only a few percent being absorbed by the glass itself and a small amount reflected. Hence in the sunshine, glass acts partly as a one-way heat valve in the opposite sense to the cooling effect of white surfaces, although for a different reason, namely transmission and opaqueness instead of reflection and emission for short- and long-wave radiation respectively.

The effect of angle of incidence on the amount of light transmitted by glass and absorbed by a black surface.—The total solar energy received by fixed glass-covered absorbers is considerably less than the total radiation impinging on a surface kept perpendicular to the direct rays of the sun throughout the day. The essential difference is that the effective reception area of a fixed surface is less than that of a normal surface in proportion to the cosine of the angle of incidence. There is also greater absorption by the glass and increasing reflection from the glass and absorber surfaces as the angle of incidence increases.

EXPERIMENTAL INVESTIGATIONS

The useful heat output of a fixed solar-energy absorber depends primarily upon the short-wave energy received, which changes rapidly during the day and differs from day to day because the intensity of the sunshine varies with the season and with the character of the atmosphere. Second, the useful heat output is affected by the heat losses of the absorber, which vary with temperature and wind. No single-day figure or curve, therefore, can be a standard. In order to compare the results of different experiments on different days, three different types of heaters (see pl. 1) were built by Charles Barbee and H. D. Lewis.[12] Simultaneous observations were made throughout the late summer and fall and are discussed in the following sections.

Ideal thin, flat-tank solar-energy absorber.—Although some of the solar energy falling in the space between pipes can be utilized indi-

[10] Fowle, Frederick E., Smithsonian physical tables, 8th rev. ed. Smithsonian Misc. Coll., vol. 88, 686 pp. (see specifically p. 383), 1933.

[11] McAdams, Wm. H., Heat transmission. 383 pp. (see specifically pp. 45–49). McGraw-Hill Book Co., New York, 1933.

[12] Staff members of the Agricultural Engineering Division, California Agricultural Experiment Station, Davis, Calif.

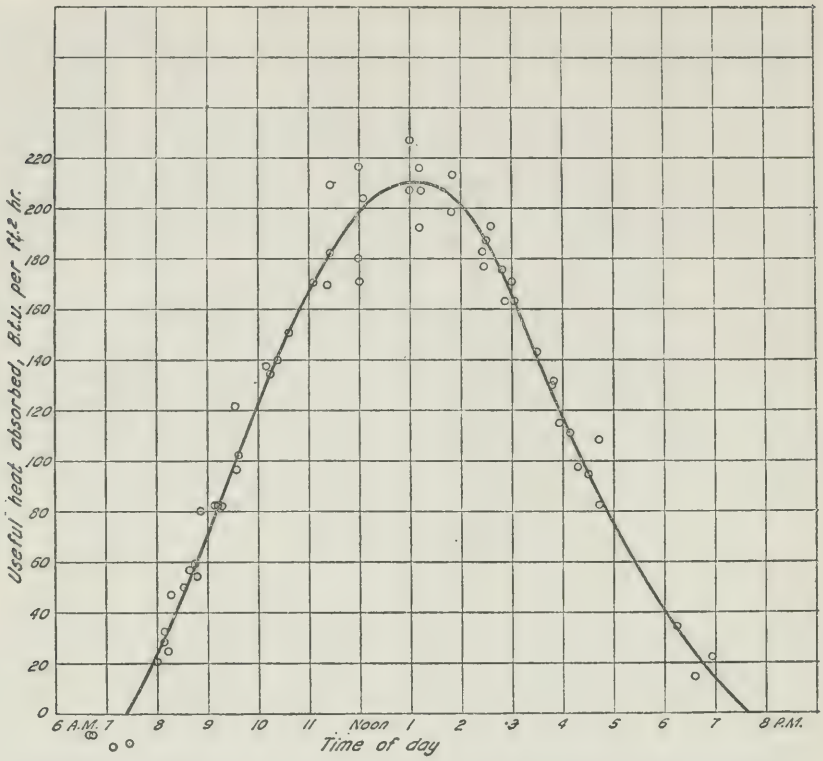


FIGURE 2.—Useful heat output of thin flat-tank absorber on clear days, September 23–27, 1935.

rectly by convection of hot air, or by conduction through a cement bed, or by extended fin surface, the ideal absorber has a continuous black surface covering a thin sheet of water. This type is seen in the center of plate 1. The inherent disadvantage of the flat tank is its inability to withstand even low water pressures without an expensive construction using heavy plate and many staybolts. Its high efficiency, due to minimum heat losses, is usually not economical in comparison with a larger, less efficient pipe absorber.

Heat output of thin flat-tank absorber.—Figure 2 indicates the useful heat obtainable on clear days near the end of the usual solar-heater season. Midsummer values would be much higher. The data for this curve were obtained with water constantly flowing through a flat, thin tank 20.9 square feet in area with a single-glass cover, as shown in the center of plate 1. The rate of flow was maintained constant at about 1 quart per minute by gravity from the float chamber seen in plate 1, above and to the left of *C*. The discharge was into an open funnel, visible at the upper left-hand corner of the flat absorber. A noon temperature rise of about 40° F. above the inlet temperature of about 80° F. occurred, and the average absorber temperature was

somewhat above average air temperature, as would be the case in a solar water heater. The total useful heat obtained per day, as indicated by the area under the curve of figure 2, was 1,360 B. t. u. per square foot. There are large heat losses from the hot absorber box and considerable heat absorption by the insulation. The latter, though not a true loss, delays and lowers the peak of the curve in relation to the theoretical input.

Exposed-tank solar water heater.—Simple, bare water boilers mounted outdoors where they will not be shaded have long been used during the summer for furnishing late afternoon hot showers. The tanks are usually horizontal or vertical, but experiments described later indicate that sloped mounting (pl. 2, fig. 1) is more effective. These exposed tanks cool nearly to air temperature at night and are useless before noon.

The temperature rise in round-tank absorbers differs from that in thin flat-tank absorbers mainly because of the large water quantity associated with a given absorber area. The common 30-gallon hot-water boiler 1 foot in diameter by 5 feet long has such a poor ratio of area to volume that the water does not warm rapidly. Since larger-capacity tanks have even poorer ratios of area to volume, and smaller diameter would be special, this study by H. D. Lewis was confined to the regular 30-gallon tanks.

Figure 3 shows the performance of exposed horizontal and sloped tanks which on calm days furnish enough hot water for two or three hot showers at 102° F. The horizontal tank on days with average air-day temperatures of 100° F. furnished 20 percent less hot water than the sloped tank even on days 10° colder. The horizontal tank is less efficient because all the sunshine falls on the hottest part of the tank. If the tank is sloped (pl. 2, fig. 1), the sun shines on the lower, cold end as well as on the upper hot end. In this case much of the colder water is heated directly at low temperature and with small heat loss. In all cases the average water temperature reached its maximum before 4 p. m.

The lowest curve (fig. 3) indicating the heat output on a cold summer day, shows the need for protecting the tank against cold air and wind; but even so there is ample water for one hot shower.

When the quantity of hot water available from a 30-gallon tank heater is not sufficient but the characteristic temperature performance is satisfactory, a larger quantity is obtained by using several tanks in parallel, with all the cold-water inlets connected together in one direction and all the hot outlets connected together in the opposite direction. The tanks should be spaced well apart to avoid the shading of one by another in the early morning and late afternoon.

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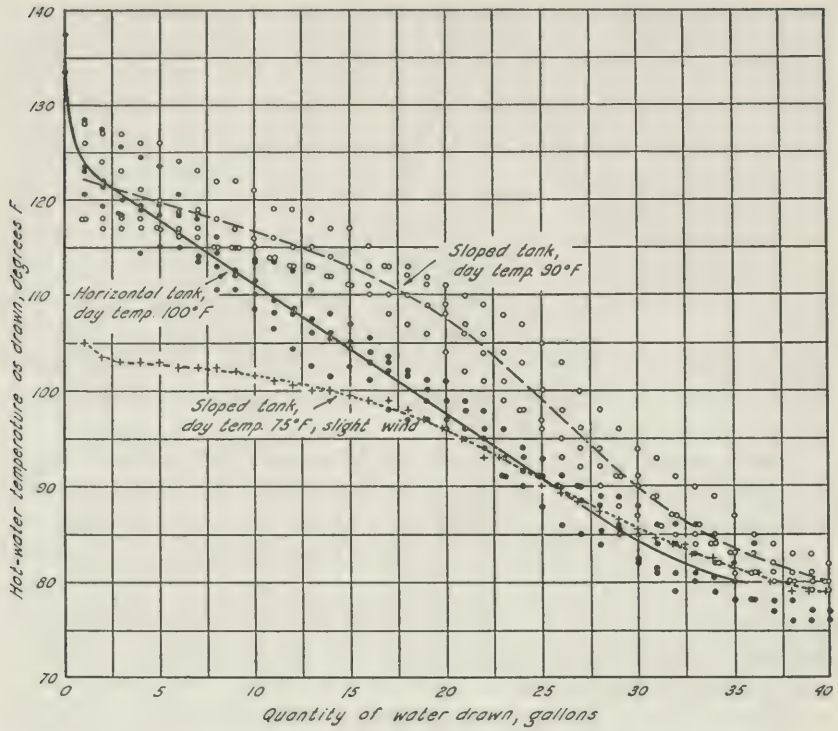


FIGURE 3.—Temperature of hot water drawn at 4:00 p. m. from simple uncovered 30-gallon tank in July; temperature readings were taken of each gallon as drawn.

Enclosed multiple-tank solar water heater.—An improvement of the exposed tank heater is seen in plate 2, figure 2. From several tanks enclosed in an insulated, glass-covered box, a large supply of water above 120° F. can be obtained in the afternoon. This system might be used for general domestic hot water if the clothes could be washed in the late afternoon when the water is hottest. During the night the water cools off so rapidly that morning temperatures are too low for clothes washing, though it yet might serve for all the other needs. The sunshine falling in the box space between the tanks and on each side indirectly furnishes extra heat for the tanks by convection of hot air. Although the daytime thermal efficiency of the glass-covered tank heaters is high, the large losses at night make the 24-hour efficiency less than for pipe absorbers with insulated storage tanks.

Temperatures over 130° F. are obtainable in the late afternoon, but the morning temperature cannot be expected to exceed 110°, which is too cold for washing clothes. This system (pl. 3, fig. 2) has, however, the advantage of simplicity, high daytime efficiency, and self-storage, and is nonfreezing in most of the agricultural areas of California.

Figure 4 shows the performance of three enclosed tanks connected in parallel. The tanks had been filled at 8:30 a. m. with cold water (67° F.). The hot-water output per tank in the insulated box at 4:15 p. m. on September 12 is better than that from the exposed tank in July (fig. 3). Furthermore, the exposed tank cooled nearly to air temperature every night; and although the water temperature in the enclosed tank dropped 25°, this drop was less than one-half the difference between the evening hot-water temperatures and the morning air temperatures. It is unfortunate that usual methods of insulation will not preserve a temperature the next morning at 8:30 a. m. high enough for efficient clothes washing.

The data for figure 4 were obtained with tin-plate reflectors under each tank so curved that all the incident light was thrown onto the tanks. The entire box appeared black from all angles except at the east and west edges. In November these reflectors were removed, and the entire box was painted black. The useful heat output with or without reflectors was 724 B. t. u. per day per square foot of glass area. The amount of solar energy received by the thin, flat absorber, was 1,020 B. t. u. during the day the triple tanks had reflectors, and 1,003 B. t. u. per square foot during the day the triple-tank box was plain black. This indicates no advantage in using tin-plate reflectors in an insulated box. The general results of all comparisons between the

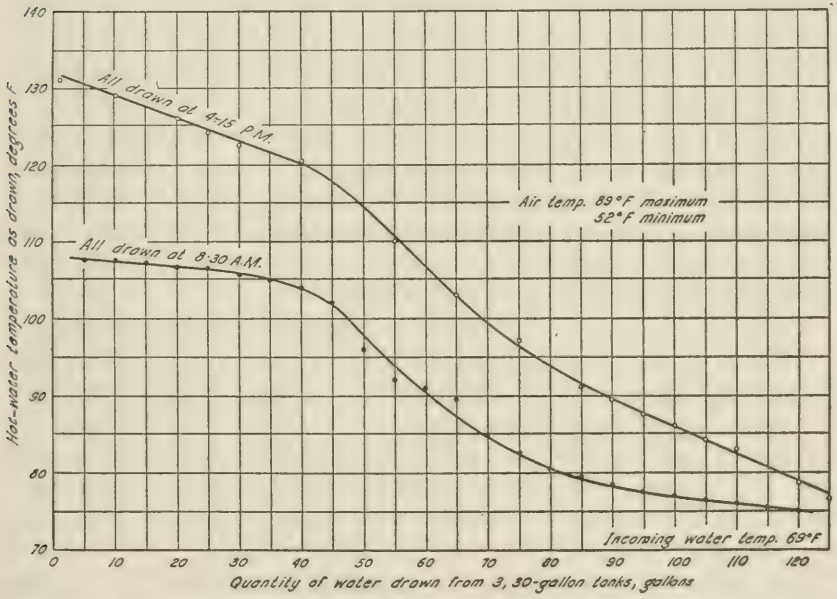


FIGURE 4.—Temperature of water drawn from enclosed triple-tank absorber, after one day's heating, at 4:15 p. m. and 8:30 a. m., September 11 and 12, 1935; temperature readings were taken of each 5 gallons as drawn.

enclosed triple tanks and the ideal thin, flat-tank absorber indicate an approximate relative efficiency of 70 to 75 percent for daytime heating.

The tanks in figure 4 were on 24-inch centers, and the inside width of the box was 8 feet.

Single-pipe absorber with storage tank.—The usual "solar heater" consists of a flat, glass-covered, zigzag pipe-coil absorber connected for thermosiphon circulation with an insulated storage tank (pl. 3, fig. 1). In this system when the storage tank is above the absorber there is no appreciable reverse circulation at night, and the high daytime temperature is conserved by the tank insulation so that temperatures over 140° F. are available at all times if the system is properly designed.

Multiple-pipe absorber with storage tank.—When the required absorber area is too large for a single zigzag pipe, the flow resistance can be decreased by installing several pipes in parallel (pl. 3, fig. 2). The heat transfer operation is more effective than for the single-pipe absorber of the same area because with the faster flow the temperature rise will be less and the heat losses from the absorber lower.

Thermosiphon circulation and temperatures in pipe absorber with storage tank.—The faults of the round-tank absorbers—namely, small absorption area in proportion to the tank capacity, and large nocturnal losses—are remedied by separating the storage tank from the absorber area. The absorber area can then be designed to satisfy the heat requirements independently of tank size; and the storage tank, being separate, is easily insulated to minimize heat losses.

The separation of absorber and storage tank requires some means of heat transfer from absorber to tank during the day and the prevention of heat loss from tank to absorber during the night. This transfer can be accomplished positively by forced circulation, using a positive pump that is operated only during the heating period. For domestic installations this system is objectionable because of expense, leaky packing glands, and the need for mechanical or electrical power not directly available from sunshine.

Solar heat itself can, however, be used for producing thermosiphon circulation if the piping system from tank bottom to absorber and back to tank top is properly designed. Water warmed in the absorber becomes of lower density than the colder water in the pipe from the tank bottom, which will flow into the absorber and push the heated water into the top of the tank. The force available for this circulation is proportional to the difference in density of the hot and the cold water.

If the absorber is well below the tank, it becomes a low, cold pocket at night and thermosiphon circulation ceases. The night losses are thus confined to the escape of heat through the tank insulation and

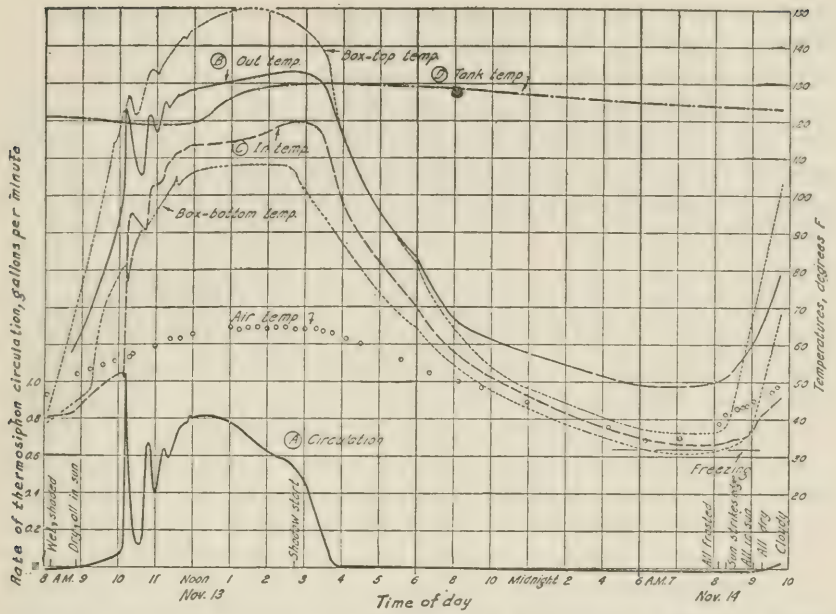


FIGURE 5.—Observed temperatures and thermosiphon circulation in a five-pipe absorber connected with a large storage tank, November 13 and 14, 1935, under a clear sky and light wind.

to the cooling of the absorber unit, which contains but little water.

The rise in temperature of the water in the absorber pipe due to the sun's heating depends primarily upon the length of time the water remains in the absorber pipe. These factors act together so that an automatic balance exists between the pipe friction and the force available from the difference in water density due to heating. If the sunshine suddenly becomes more intense, creating an excess in temperature differential, the increased difference in water density provides more force to make the water flow faster; and then it will be in the absorber for a shorter time and will be warmed to a lower degree, thus balancing any temporary temperature excess.

Figure 5 shows the observed temperature differentials and rates of circulation for a five-pipe absorber connected to a storage tank with the hot circulation inlet 7½ feet above the center of the absorber. The rate of flow, curve *A*, was determined by the deflection of a vane suspended in a horizontal glass tube, previously calibrated.

Circulation begins slowly at 9 o'clock, gradually pushing the cold water in the vertical riser into the tank. Then suddenly, an hour later, a surge occurs when the hot water, too long in the absorber, fills the vertical riser, while the very cold water due to night cooling still fills the vertical part of the pipe from the tank to the bottom of

the absorber; thus a maximum temperature differential is provided. This surge quickly dies away as unheated water rushing through the absorber fills the vertical riser while hot water from the tank is drawn into the vertical drop; thus a temporary minimum temperature difference is created. Another smaller surge occurs later for similar reasons, and then, except for a minor surge at 11:15, the circulation builds up steadily to a maximum at noon. It gradually falls off thereafter as the tank water warms up and the solar intensity decreases. The flow stops rather suddenly when the absorber becomes shaded. Because of nocturnal cooling of the vertical riser which enters the tank 4 feet above the pipe to the bottom of the absorber, slight reverse circulation occurs, reaching a maximum about sunrise.

The temperatures of the water leaving and entering the absorber are shown by curves *B* and *C*, respectively. These reflect the flow surges previously described. The temperature difference between *B* and *C* does not indicate properly the driving force for the circulation, because of the importance of the water density in the vertical riser shown in plate 1 from points *B* to *C* and in the vertical part of the cold pipe from tank bottom to pipe-absorber bottom at point *A* of plate 1. The relation observed in figure 5 between the outlet temperature *B* and tank-center temperature *D* shows the mutual dependence of the two. This 120-gallon storage should have had an absorber nearly three times as large as the experimental 40.3 square feet, so that the daily rise in tank temperature would be much steeper. Then *B* and *C* would also rise much more sharply during the day because the water will not flow from the absorber into the tank unless the absorber is hotter than the tank. Practically, the tank temperature *D* shown in figure 5 is what might be expected in a full-sized installation when about 100 gallons of hot water are gradually drawn during the day.

The rate of heat input to the storage tank is influenced by the temperature of the tank water, because a high inlet temperature means greater losses from the absorber box. This change, however, is not so important in limiting the maximum storage-tank temperature during nonuse of hot water as is the continual heat loss 24 hours a day from the hot tank and absorber to the colder air and surroundings.

The temperatures inside the absorber box at the top and at the bottom are included in figure 5 to indicate the heat transfer by air convection from the black bottom to the pipes. The minimum box temperature was 4° F. below minimum air temperature and the glass was frosted at sunrise although the pipe did not quite reach freezing. This absorber was exposed during the entire winter of 1935–36 at Davis and did not burst although a minimum air temtemperature of 25° F. was recorded. This, however, cannot be considered safe practice.

Size of absorber in relation to quantity of water to be heated.—The average daily heat absorption on clear days in September can be judged from the curve of figure 2 to be approximately 1,400 B. t. u. per square foot of glass for a flat-tanker absorber. Such an absorber although most efficient, is not practical because of its tendency to deform when subjected to internal pressure. A larger-area pipe absorber is more economical, and shows a simultaneous daily heating of approximately 1,000 B. t. u. per square foot of glass. If a supply water temperature of 65° F. is assumed, each gallon of hot water will require about 700 B. t. u. for heating. The night losses are about 100 B. t. u. per gallon of high-temperature water, making a total daily requirement of about 800 B. t. u. per gallon. As some allowance must be made for dust on the glass and for desired operation when the sky is not entirely clear, an arbitrary figure of 1 square foot of pipe-absorber glass area per gallon of hot water can be assumed adequate for satisfactory solar-heater operation for 7 or 8 months of the year.

LENGTH OF PIPE RUN FOR SATISFACTORY THERMOSIPHON PERFORMANCE

There is considerable difference in hot-water temperature at the top of the tank when using single zizag and when using parallel pipe absorbers, especially over a short heating period. With the single-pipe zigzag small quantities of water hot enough for the small demands are available long before the whole tank temperature builds up with the rapid-flow type.

For the rapid-flow type where it is desired to heat the whole tankful as quickly as possible, probably a 30° F. minimum temperature rise should be obtained by noon. The experiments indicate that this can be accomplished on cloudless days with single ¾-inch pipes about 70 to 100 feet long when the absorber discharges into the storage tank 7½ feet above the center of the pipe absorber coils, and the pipes to and from the storage tank are 1¼ inches for three or four parallel pipes and 1½ for five or six parallel pipes. Large variations will occur, determined by the number of return bends, the height of storage-tank connections, and the weather conditions. When this arbitrary criterion is applied to pipe absorbers containing 4 or 5 lineal feet of ¾-inch pipe per square foot of glass area (and per gallon of storage-tank capacity), with the bottom of the tank 2½ feet above the center of the absorber, a 45-gallon system should have three or four pipes in parallel; a 60-gallon system, five or six pipes. In larger systems the storage tank may be raised to obtain greater thermal head. Each pipe run should be about 10 or 15 feet per foot of effective riser height from center of absorber to discharge into storage tank.

For the quick heating of small quantities of water the single pipe runs should be longer or a valve used to restrict the rate of circulation. Copper tubing is often used for this service and is advantageous on partly cloudy days because of its relatively low heat capacity. Some domestic waters attack copper.

In many houses there is no room in the attic above the top of the absorber coils for the storage tank. In such cases a false chimney can be built around the storage tank above the roof.

NONFREEZING SOLAR-ENERGY ABSORBERS

A solar heater used in combination with an automatic heater can be operated to advantage throughout the winter if the danger of pipe absorber freezing can be avoided. There is not much danger of freezing during ordinary nocturnal radiation frosts on calm, clear nights when the air temperature remains only a few degrees below 32° F. for a short time (fig. 5) because of the high heat capacity of the pipe, water, and insulation. Freezing temperatures with wind, however, are almost sure to do damage unless there is considerable reverse circulation at night drawing warm tank water through the cold pipes. Such reverse circulation occurring with low-level storage tanks is ordinarily very objectionable in wasting heat previously absorbed. Usually the ordinary pipe absorber must be drained during periods of freezing temperatures if damage is to be avoided. If frost warnings are not received regularly, it is good practice to drain the absorber as soon as the weather is cold enough for house heating.

When it is desirable to operate a solar water heater on bright days during the winter, the danger of bursting absorber pipes during cold nights can be avoided by separating the absorber circulating fluid from the usable water in the storage tank, and using a nonfreezing solution in the absorber circuit. Figure 6 shows a commercial storage tank with separate heating-fluid jacket which is the only significant difference from the ordinary system of pipe-coil absorber with circulation directly through the storage tank. Standard tanks with internal heating coils or with external heat exchangers might also be used.

Commercial nonfreeze type solar water heater.—The usual commercial type solar heater is of the type in which a nonfreezing solution is used in a separate circulating system (fig. 6). In one of these designs [13] the absorber fluid flows through the jacket space around the storage tank and does not mix with the usable hot water. This circulating fluid merely transfers heat from the pipe absorber to the storage tank, and being separate from the usuable water in the storage tank it can be any suitable nonfreezing solution. Standard tanks

[13] Day and Night Water Heater Co., Day and night solar water heater (advertising circular). Monrovia, Calif., 1932.

with internal coils but without stratification shields can be connected (fig. 6) with an expansion chamber for the separate nonfreezing circulating fluid, but will not give high-temperature water quickly.

Separate fluids for nonfreezing solar-energy absorbers.—Various ingredients can be added to water to lower its freezing point. The most common solutions are alcohol mixtures and brines. Other fluids not having the freezing characteristic of water might also be used, notably oil. Addition of alcohol to water is the simplest nonfreeze expedient; but as the alcohol vaporizes rather easily in a solar heater

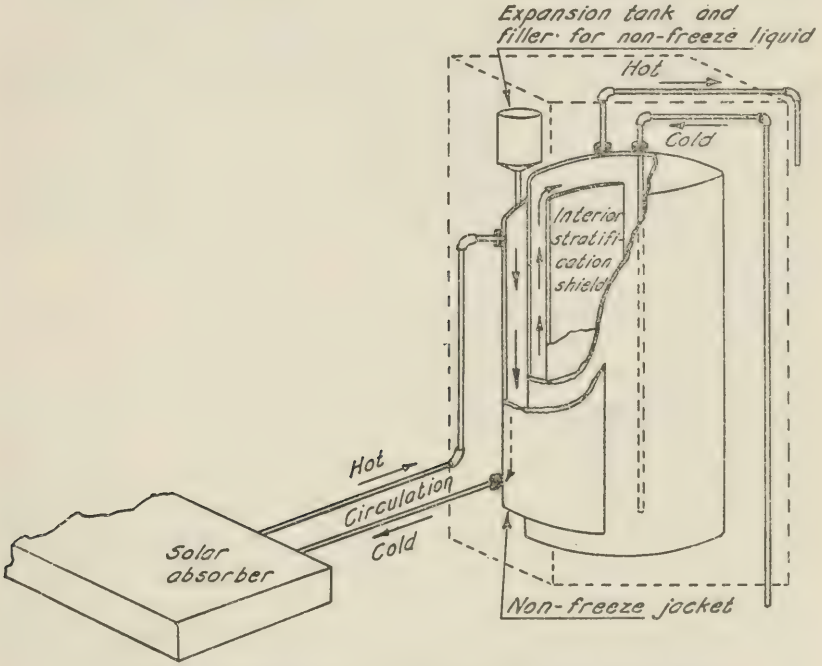


FIGURE 6.—Commercial type nonfreezing solar-heater-system tank.

and the solution weakens, some addition should be made every fall. Various brine solutions, widely used industrially for refrigeration, are recommended for nonfreeze solutions only where the operator is familiar with the operating technique to avoid corrosion in black iron pipe. The lightest grade of highly refined spray oil is the most suitable of the petroleum products, but does not circulate readily under thermal density differential head, being only one-fifth as effective as water as a thermosiphon heat-transfer medium. This means that the absorber when filled with oil would operate at much higher temperature than when filled with water and would be less effective because of larger absorber heat losses unless forced circulation is used.

HOT-WATER DEMAND

The decision as to the kind, size, and system of solar water heater to be installed depends upon several interrelated factors. The nature of the hot-water demand is, of course, the primary question. This demand involves temperature, quantity, and time of day; it varies widely in individual cases, because of differences in personal habits, plumbing facilities, and the relative expense of heating water.

Temperature of hot water needed for various domestic purposes.—The desirable temperature of water used for various purposes is known within reasonably close limits. The temperature data in table 1 were observed in common domestic practice. The water for a hot shower is definitely too hot at 105° F. and verges on the cool at about 90° F. Dishwater at 120° F. requires the use of a mop because it is too hot to keep the hands in; and although dishes can be scrubbed clean in cold water every housewife would object to dishwater below 105° F. Assuming the usual temperature of the supply water to be 60° to 70° F., the difference in the amount of heating required to obtain the upper and lower limits of temperature is only about 25 percent.

Quantity of hot water needed for various purposes.—The variation in quantity of water used, however, is so great that no average assumption can be considered narrowly. If unlimited inexpensive hot water is readily available at the turn of a faucet, its use will be almost extravagant; the water will be left running while one is doing short chores, tubs will be filled to overflowing, showers will be run to heat bathrooms, and so on. If, on the other hand, a person must wait while water is being heated or must make an effort to obtain hot water or finds that hot water is expensive, he naturally will use a minimum. The quantity of hot water obtainable from a solar heater varies with the amount of sunshine available; and to make up a deficiency by starting an auxiliary heater involves a time delay, personal effort, and expense so that the natural use tends to follow the available supply. This elasticity of demand greatly extends the period of usefulness of solar water heaters both before the summer and afterward into the autumn, often until a water coil in the range or furnace can be depended upon during the winter (fig. 7).

Despite the inherent variations in personal habits one must assume some average hot-water demand in order to estimate the size of water heater that will give adequate service without being unduly large.

For late afternoon hot showers for field workers, a temperature of 102° F. is needed, and a minimum quantity of 12 to 15 gallons per person. This is usually obtained by simple water tanks exposed to the sun (pl. 2, fig. 1).

For general domestic purposes the average rural demand is usually considered approximately 40 gallons of hot and cold water together

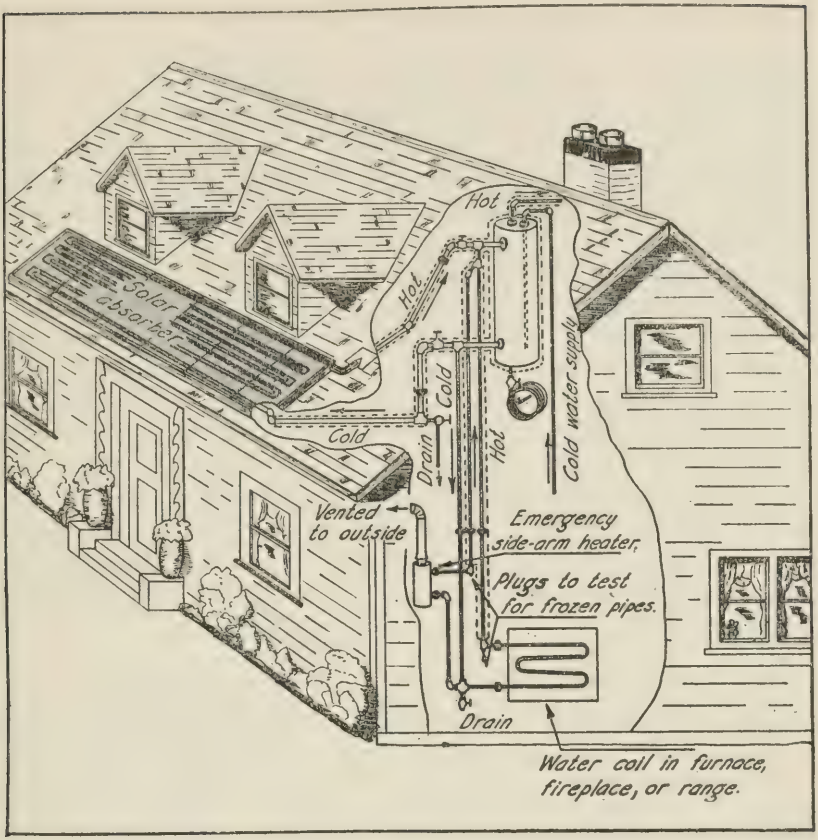


FIGURE 7.—Solar absorber and furnace coil with single storage tank.

per person per day. of which one-third is assumed to be heated. The American Society of Heating and Ventilating Engineers recommends an estimate of 40 gallons of hot water per person per day for apartment houses. This difference of 3 to 1 is due largely to the convenient availibility of hot water in apartment houses equipped with steam boilers operated by a janitor.

The data in table 1 were obtained by J. R. Tavernetti from a test installation of a low-wattage electric water heater for the California Committee on the Relation of Electricity to Agriculture. These metered observations covering the daily springtime routine for a family of two adults, two small children, and a baby give a direct intermediate example of hot-water use when an adequate supply is always available from a solar heater operated in series with an automatic electric water heater, which was considered expensive to operate. All figures include the quantity wasted in warming approximately 40 feet of cold pipe.

If the family is considered as equivalent to four or five adults, the average total daily hot-water demand is approximately 20 to 25 gallons per person. This figure, though much greater than the accepted rural average, is only 50 to 60 percent of the demand recommended by the American Society of Heating and Ventilating Engineers for apartment houses. Nevertheless, the observed total coincides with the general recommendations of a manufacturer of commercial solar water heaters.

Recognizing that the figures in table 1 represent neither a scanty nor an extravagant use of hot water, one notes that 58½ gallons of hot water is needed in the first 3 hours on wash days (three times a week); then only 14½ gallons is used in the following 5½ hours, with no demand at all for the next 3½ hours. Then another heavy demand of 49½ gallons of hot water comes with the evening baths, usually within 3 hours. Obviously, the solar heater cannot meet the first demand of 60 gallons early in the morning without an insulated tank to keep hot the water heated the previous day. Since, furthermore, the evening baths will be taken from this storage of hot water needed in the morning, the storage tank should be large enough, as a general rule, to hold the entire day's requirement.

TABLE 1.—DAILY HOT-WATER DEMAND FOR A FAMILY OF 5

Time	Use	Temperature, degrees F.	Quantity of hot water, gallons
7:00 a.m.	Shaving and incidental	100	4, plus cold blend.
8:00–8:30 a. m.	Clothes washing, 1 machineful reused	128	14.
8:30–9:15 a. m.	Dishwashing	128	12.
9:30 a. m.	Washing clothes by hand in sink	120	3½, plus cold blend.
9:15–10:00 a. m.	4 trays rinse water	100	22, plus cold blend.
10:00 a. m.	Baby's bath	100	3, plus cold blend.
10:15–11:30 a. m.	Incidental		3.
11:30 a. m.–3:30 p. m.	Washing dinner dishes and incidental	125	11½.
7:00–7:30 p. m.	2 children's baths	92	25, plus cold blend.
7:30–8:30 p. m.	Washing supper dishes	[1] 125	7.
8:30 p. m.–6:30 a. m.	2 adults' baths	95	17½, plus cold blend.
	Washday total		122½ gallons hot water
	Average daily total		96 gallons hot water

[1] An electric dishwasher requires 150° water to sterilize, but water 160° F. or hotter causes trouble. The total quantity including the preliminary spray (waiting for water to run hot) averages 5 or 6 gallons per charge. Usually an additional 3 gallons is used simultaneously for washing pans and for incidental cleaning up.

INSTALLATION AND CONSTRUCTION OF SOLAR WATER-HEATER SYSTEMS

In suitable locations in the South and West a solar-heater system properly designed and installed will by itself adequately furnish hot water continually throughout the summer for domestic use. In the winter, however, some auxiliary means for heating water is usually desirable.

COMBINATION OF SOLAR HEATER AND FURNACE OR RANGE WATER COIL

In the most economical water-heating system (fig. 7), the solar heater is depended upon from early spring to late fall; then, during the winter, the furnace coil or water-back in the range is used for obtaining hot water. If the furnace or range is in daily use, usually the solar heater is shut off and drained to avoid freezing.

Location and connection of solar absorber.—The solar absorber is most conveniently placed on a roof sloping south and in front of attic windows so that the glass cover can be readily cleaned with a hose (attached to the storage-tank drain) or with a mop. The usual absorber construction is similar to that of a skylight, but with a special provision for an insulated pipe outlet at the top that permits a continuous rise in the pipe to the storage tank. This requirement usually interferes with standard flashing practice. A simple method is shown in figure 7; the hot pipe is brought through the end of the absorber above the roof surface and turned to enter the attic through a separate hole higher in the roof, the pipe being insulated and enclosed in a lead sheath under which the rain water can pass from around the top of the absorber. The flashing around the lead sheath where it pierces the roof is separate from the flashing around the absorber box. In an alternative method, the hot pipe leaves the top edge of the absorber through a special box running from the roof slope out to the absorber frame, with the roof flashing arranged to drain each way from this obstruction along the top edge of the absorber.

Safe piping practice for furnace or range coil.—Valves between the tank and the cold-water supply line and between the auxiliary heaters and the tank are intentionally omitted to avoid danger of bursting. If a valve were provided in the supply line to the hot-water tank, the tank might be drained to avoid freezing; and later the range or furnace might be thoughtlessly started with all valves closed and result in an explosion. A single valve at the meter, shutting off all the water, is not objectionable, for the cold-water supply is always turned on before one thinks of starting a hot-water heater. If hot-water shut-off valves are to be installed, recommended dairy sterilizer connection practice should be followed, which specifies a check valve in a bypass around each shut-off valve so that in case of higher pressures in heaters the water can back up in the supply line even though the manually-operated valves are closed. This bypass and check-valve system permitting reverse flow is alternative to the pressure relief valve, which might not operate properly after long periods of nonuse.

Valves between the solar absorber and the tank are necessary to permit draining the absorber in cold weather without disturbing the rest of the hot-water system. These valves do not create a danger from overheating because the heat losses from very hot absorbers usually balance the solar-energy input at a temperature below the boiling point. If the absorber coils are filled with water that is confined by closed valves, solid expansion by heating might produce serious breaks if there is no entrained air; but this is not dangerous, as is the explosion of a closed dry boiler heated by a fire.

Whenever the water freezes in the pipes between the storage tank and furnace or range coil, there is another serious danger of explosion when a fire is started. The use of tees instead of elbows at the upper connections to heating coils makes it easy to inspect by loosening the plugs and draining enough water to notice whether the pressure remains constant.

With gravity-flow water-supply systems, the highest pipe in the solar-heater system must be considerably lower than the bottom of the water-supply tank to insure full lines for thermosiphon circulation.

Installation of extra emergency side-arm heater.—The combination of solar heater and furnace or range coil works well during the summer and the winter. During a few days in the spring and fall the sunshine is not sufficient to produce water temperatures high enough for clothes washing. On such occasions washing is postponed until the morning following a bright day, or else an emergency side-arm heater (fig. 7) is used.

An extra heater of this type when connected in the furnace coil line often leads to unsatisfactory operation of both heating coils unless the hot-water pipe from each heater is carried separately into the storage tank or connected together very near the tank. This high connection satisfies the requirement that the thermal density differential head in each heater riser be greater in proportion to the total circulation head than the ratio of heater and riser-flow friction to the friction in the complete circuit. One should remember that the flow friction in the heating coil often increases rapidly because of scale formation, thus requiring a higher connection point.

Combination of solar heater with automatic water heater.—When a continual supply of hot water is essential during cloudy weather and the use of a furnace or range coil is not desirable, an automatic heater can be installed in the same manner as the side-arm heater. Since an automatic heater is completely adequate by itself, the only advantage of the solar heater combination lies in the possible saving of fuel. Often the fuel cost for an automatic heater is less than the carrying charges on the investment for a complete solar heater system with glass-covered pipe absorbers.

CONSTRUCTION OF SOLAR ENERGY ABSORBERS

Essential features of solar absorbers are the absorber pipes or tanks, the insulated box, and the glass cover. The angle of slope toward the south is not very important except that for winter operation the slope should favor the winter sun, which at noon is only about 30° above the horizon in California. Most solar absorbers are placed on sloping roofs and it is much simpler to keep the same slope than to provide a special slope for the absorber. In case of new construction, seasonal solar heaters should be placed on roofs of ¼ to ⅓ pitch, and all-year absorbers on ⅓- or ½-pitch roofs.

The construction details for the insulated box should conform to regular structural practice, and many different designs will give excellent results if simple requirements are met. Separate boxes mounted in the yard where there is no shade or on a pergola do not differ much in structure from the common roof box.

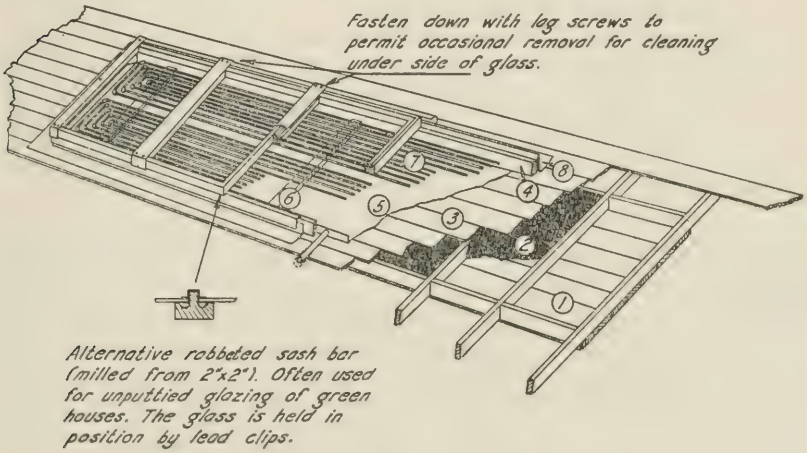


FIGURE 8.—Construction plan of pipe-absorber roof box.

Construction procedure for a built-in absorber box on a new roof.—When absorbers are built right into the roof structure the simplest procedure (fig. 8) is to (1) sheathe solid the underside of the rafters; (2) fill the rafter space with bulk insulating material such as glass wool, or the equivalent; (3) solid-sheathe on top of the rafters the same as for regular roofing; (4) frame in the sides of absorber box; (5) lay galvanized iron pan with edges turned up and bottom soldered and provided with screened drain pipe to carry off possible leaks from pipe joints or broken glass; (6) nail on furring strips to support pipe coils or tanks; (7) install pipe coils, being sure of a continuous rise from bottom to top; (8) flash around the

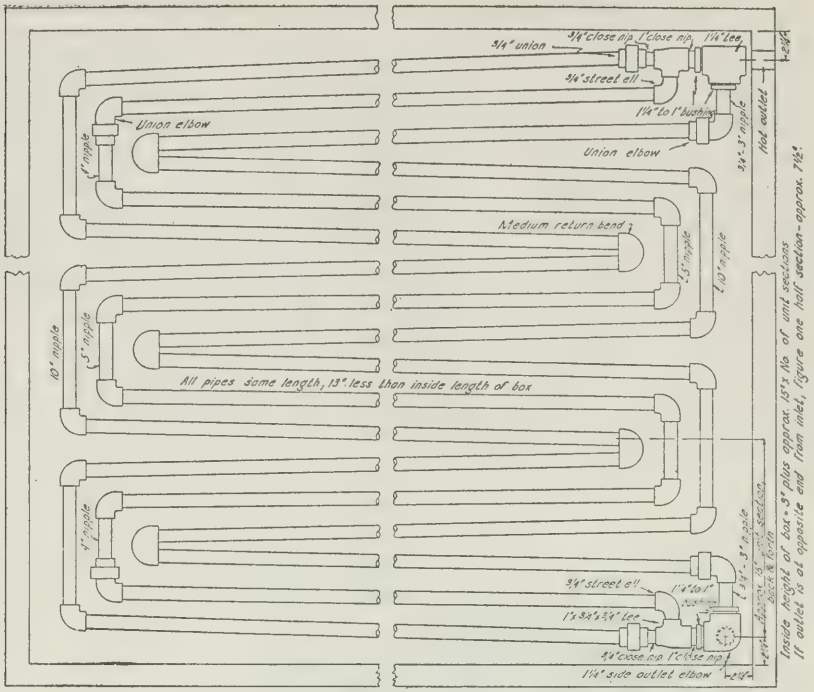


FIGURE 9.—Absorber piping diagram for three pipes in parallel.

outside; (9) paint black all over; and (10) glaze in accordance with regular skylight practice.

Removable glazed cover.—The glazed frames must be removable for spring cleaning of the under side of the glass and for servicing the pipes or tanks in case of trouble. It is also desirable to place the solar heater in front of an attic window to facilitate cleaning of the outside surface, which in some localities should be done as often as once a month.

The shape of the absorber depends upon the glass sash used. Hotbed sash 3 x 6 feet is the cheapest but has considerable wood area; four sashes would be needed for a 60-gallon system. If the absorber box can be long, single-light window sash 18 x 48 inches can be used, 12 being required for a 60-gallon system. In this case the puttying at the bottom must be brought up on the glass far enough to drain off the water when the window sash is in its sloped position. In all cases the pipe must rise continuously from the drain to the storage tank. Any dip in the absorber coils will form an air pocket and seriously interfere with the thermosiphon circulation.

Parallel-pipe absorber coils.—The common pipe absorber is a zigzag of ¾-inch pipe, and this is suitable for small solar heaters. If

the total length of pipe in the single-coil type is so long in comparison with the effective riser height that thermosiphon flow is unduly restricted and provides only very small quantities of excessively hot water, the solar-absorber heat losses are large because of operating at unnecessarily high temperature. One can then improve the efficiency by paralleling the absorber pipes to reduce the length of each line and also to divide the flow into multiple paths.

Figure 9 shows the fittings and pipe lengths for three-parallel-pipe absorbers. The combination of fittings shown gives the closest pipe spacing possible and a practical covering of absorber area. The methods shown of making the terminal connections also permit the use of all equal-length pipe runs from end to end. In the three-pipe systems one union is located at the opposite end of the box, top and bottom, to preserve the equal-length feature of the main pipe lengths. The diagram, though not complete, gives the unit-section dimensions so that the full installation can be easily sketched. Such pipe sys-

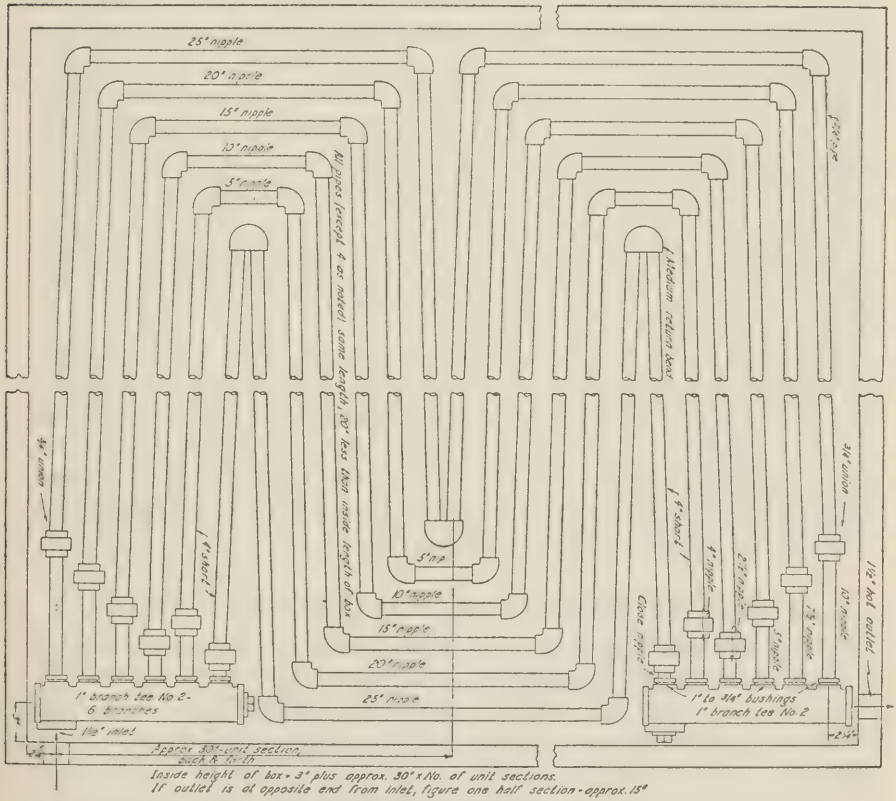


FIGURE 10.—Absorber piping for six pipes in parallel using branch T terminals.

tems have, of course, considerable flexibility; the unit sections are easily stretched out or compressed a little, and ordinary inaccuracies in pipe lengths will give no trouble.

Figure 10 shows the six-parallel-pipe absorbers using the standard branch T connection for the terminals. Complicated systems of separate pipe fittings might be used, but the 1½ inlet and outlet fitting is too large to maintain the close pipe spacing shown in figure 9. Branch T's were commonly used for industrial wall pipe radiators, but because of the present preference for cast radiator sections these branch T's are not always carried in stock by plumbing-supply houses. They are, however, readily obtainable on order and give a much neater pipe absorber. With the branch T's the two pipes connecting at the ends must be shorter than all the rest to allow for the unions.

Methods of obtaining greater heat output from limited absorber area.—Usually the most economical method of obtaining greater heat output is to increase the absorber area and extend the simple pipe coils. When, however, the available space for a solar absorber is limited, the equivalent of about 20 percent greater absorber area can be obtained on cloudless days by embedding the ordinary pipe coil to half-pipe diameter in cement mortar. This arrangement provides a means of transfer for the heat generated in the space between the pipes to the pipes themselves. A suitable concrete mixture is made of 1 part cement and 4 parts sand. After the cement has dried, the whole surface should be painted black.

Such a bed of concrete is a disadvantage on partly cloudy days because the additional heat capacity delays the warming up of the absorber when the shading passes.

Thin flat tanks covering the entire absorber area need have only 70 percent of the area specified for ordinary pipe coils. This type of equipment can be made to order and might prove advantageous for nonfreeze-type solar absorbers in which the circulating fluid is not subject to high water pressure. The proper thickness of metal and the number of staybolts required depend upon the size of the absorber units and the height of the overflow pipe.

INITIAL COST AND CARRYING CHARGES OF SOLAR WATER HEATERS

The sunshine is free, and every surface exposed to the sun is heated at no cost, but to obtain useful energy for heating water some apparatus is necessary and this usually requires an expenditure which connotes an interest charge. Then, too, the apparatus deteriorates because of rusting and exposure, so that some annual depreciation charge also should be considered. There are operation costs, even though very low, because of the care required for cleaning the glass and replacing occasional broken panes.

The heat output of a solar water heater cannot be specified exactly in comparison with auxiliary heaters because the auxiliary heater is operated only when needed, whereas the solar heater, operating whenever there is sunshine, is of value only when used.

In many places, such as isolated cabins or houses where the fire hazard of auxiliary water heaters is objectionable, the relative cost of solar heaters is not important. In other cases where full automatic water heaters are needed anyway, the carrying charges of a solar absorber must be compared with the bare cost of fuel or electricity it saves.

Cost of commercial solar water heaters.—The nonfreeze commercial solar water heater with special tank is sold at the factory for about $3 per gallon capacity. The installed prices, including insulation, extra pipe and fittings, labor, and the like are about $5 per gallon. The small systems have a slightly higher cost than these figures.

By assuming a useful life of 18 years and servicing costs for renewal of alcohol and repairs at 4 cents per gallon capacity a year the total annual cost will average about 47 cents per gallon capacity a year. Each gallon capacity represents a free heat absorption of about 1,000 B. t. u. per day, and the nonfreeze type can be assumed to be fully operative for about 270 days a year. These assumptions indicate a solar heat cost per 1,000 B. t. u. of about one-sixth cent, which is equivalent to an electricity rate of 6 mills per kilowatt-hour when fully utilized.

Cost of common pipe-coil solar water heater.—A standard pipe-coil solar heater system (fig. 7) can be installed for about $3 per gallon capacity. By assuming for this type a useful life of about 15 years and 210 days per year of full operation, the solar heat costs about one-ninth cent per 1,000 B. t. u., which is about equal to the fuel cost when using natural gas in the Sacramento Valley.

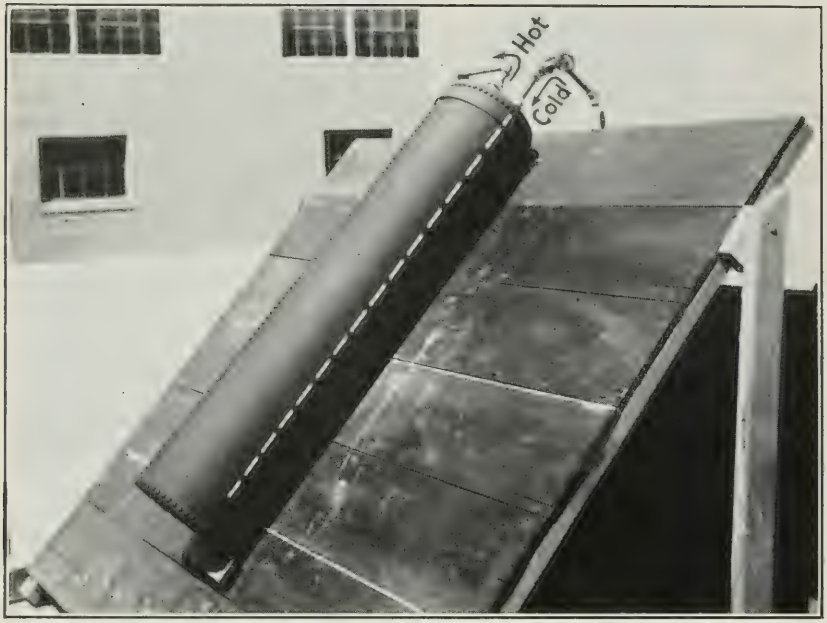
If the solar-heater system is installed by the owner and the cost considered is that for materials only, these annual carrying charges might be halved, in which case the solar heater would compete economically with the manual fuel-oil heater, which is bothersome and a fire hazard.

Cost of solar absorber tank heaters.—The 30-gallon range boilers, hotbed sash, and insulation can be obtained for about 60 cents per gallon for the enclosed tank heater shown in plate 2, fig. 2. If fully utilized, this installation furnishes hot water at a cost of about one-twenty-fifth cent per gallon. The least expensive system, the exposed second-hand tank (pl. 2, fig. 1) for afternoon showers, heats water on sunshiny days for no appreciable cost.

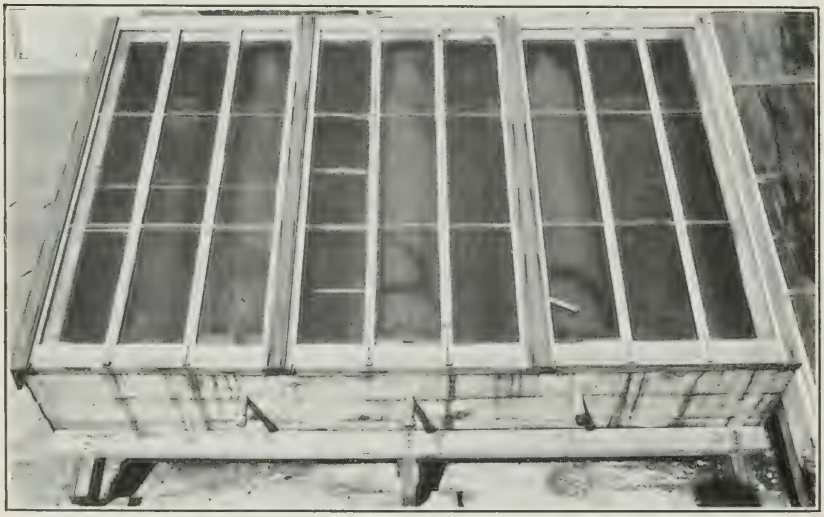


THREE EXPERIMENTAL SOLAR WATER HEATERS WITH ELEVATED STORAGE TANK.

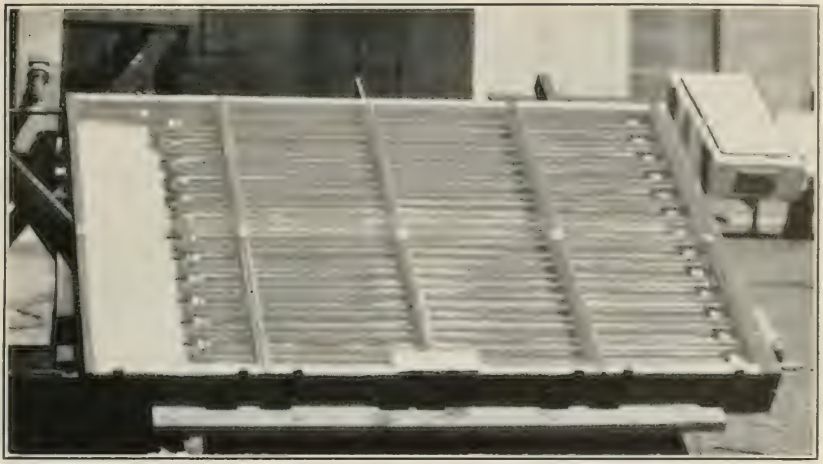
At the left is the enclosed triple-tank heater shown in pl. 2, fig. 2. In the center is the thin flat-tank absorber used for reference. At the right is a pipe-coil absorber (also shown in pl. 3, fig. 1) with connection at *A* from the bottom of the storage tank. Above the pipe-absorber outlet *B* there is an insulated vertical riser to *C*, where it turns to enter the top of the storage tank.



1. EXPOSED BARE TANK SUITABLE FOR HEATING WATER FOR LATE AFTERNOON SHOWER BATHS ON HOT, CLEAR DAYS.

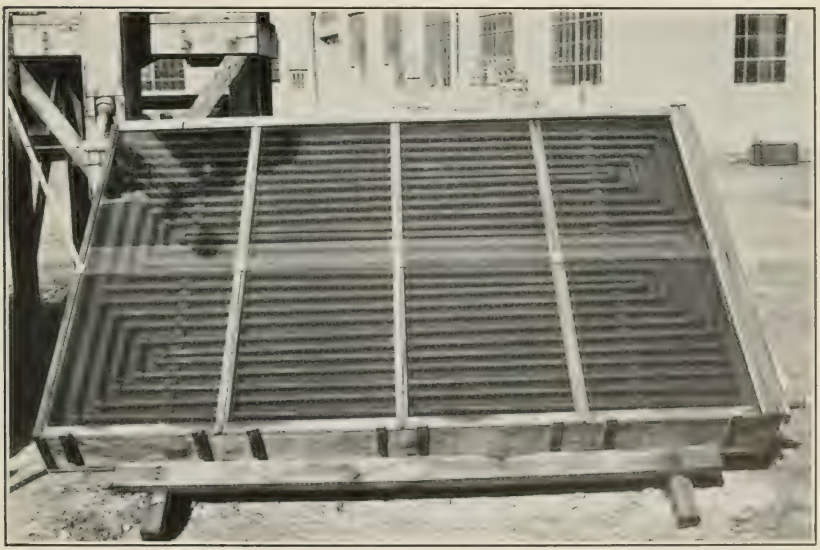


2. TRIPLE-TANK ABSORBER IN INSULATED BOX WITH HOTBED SASH COVER.



1. SINGLE-PIPE SOLAR-ENERGY ABSORBER FOR SMALL INSTALLATIONS.

A black background and proper length of box as seen in fig. 2 (below) are recommended instead of the experimental reflector-bottom shown in this photograph.



2. MULTIPLE-PIPE SOLAR-ENERGY ABSORBER, SHOWING BRANCH-T METHOD OF CONNECTING PARALLEL PIPES.

THE FRINGE OF THE SUN[1]
NEBULIUM AND CORONIUM

By C. G. James

[With 5 plates]

On the clear serene night of August 20, 1864, Sir William Huggins was working in his observatory at Tulse Hill. His 8-inch refracting telescope had been fitted with the Royal Society's new spectroscope, an improved instrument which Huggins himself had perfected for astrophysical research. The telescope was first directed at the planetary nebula in Draco and afterward at the great nebula in Orion, and Huggins saw with keen satisfaction, and no little excitement, that the light from these nebulae was split into a bright line emission spectrum, very faint but shown unmistakably by the precise spectroscope he was using.

This, indeed, was a great discovery, for as Huggins said, "These nebulae are shown by the prism to be enormous gaseous systems"—a point which had often been debated. For though, before Huggins, the speculative Laplace and the more prudent and practical observer Herschel had expressed the same opinion, there were many astronomers who thought that, given a large enough increase in telescopic power, all of the nebulae would eventually be shown as star conglomerates, even as at that time the giant reflector of the Earl of Rosse had exhibited one or two of the nebulae thus partially resolved.

In all, Huggins investigated 70 nebulae spectroscopically, and he showed that one-third of these were gaseous. The rest, possessing as they did continuous or absorption spectra, were found to be either star clusters or consisting partly of stars in different stages of evolution or decay. But of the Orion nebula, about which there had been much discussion, Huggins wrote, "The light from the brightest part of the nebulae near the trapezium was resolved by the prisms into three bright lines in all respects similar to those of the gaseous nebulae."

Some of the spectra lines of the whole of the Orion nebulae showed that hydrogen was present, while further inquiry identified lines

[1] Reprinted by permission from Discovery, n. s., vol. 2, No. 12, pp. 127–134, 1939.

characteristic of various other known elements. But there were two lines noted in the green that evaded identification, and the elusive matter that emitted light of those particular wave-lengths resisted all attempts made by astrophysicists to pin a label to it. These unidentified lines were later found in the spectra of many of the gaseous nebulae and, with improved instrumental power coupled with photography, similar unidentified lines were also found and ascribed to the same mystery element. The strong pair of lines in the green portion of the spectrum have been designated N_1 and N_2, their wave lengths being λ 4959 and λ 5007. There is another line λ 4363; yet another close pair occurs in the ultraviolet end of the spectrum.

The nineteenth century astronomers originally assumed that these lines were the hallmark of an element which had not then been discovered terrestrially. In fact it was given the atomic weight "three" in the scale of the elements, and was named nebulium—the gas of the nebulae. As one writer put it, "The recognition mark of nebulium is a vivid green ray by the emission of which it is known to have a concrete existence."

Afterward, the question arose as to whether this green shining gas, this "element" that had cropped up so unexpectedly in outer space, was really something that had evaded chemical discovery on earth. Was it something more primitive? It must be confessed that, in many cases, speculation overrode sound scientific method, and it was suggested in several quarters, and by good authorities, that this celestial radiance might be due to the primeval protyle or "world-stuff," the cosmic protoplasmic fluid from which the universe had been manufactured in the beginning. Indeed, Professor Stokes went so far as to state, "It may possibly indicate some form of matter more elementary than we know on earth * * *"

However, the investigation of nebulium continued, and as new elements were discovered, so were their emission spectra lines matched with those of nebulium. But to no purpose. None were found to coincide. The gaps in the table of elements became fewer and fewer; hope began to fade. It gradually came to be accepted that the hypothetical nebulium was some familiar gas clothed in an unfamiliar fashion.

And so it proved. This assumption was made, and the problem strongly attacked by Dr. Wright at the Lick Observatory. The assault was continued by I. S. Bowen, and nebulium began to shed its cloak of mystery. Bowen, in 1927, showed by the use of modern atomic theory, and by elegant mathematical reasoning, that first, the lines of nebulium were of the variety that require a huge amount of energy for their excitation. Second, the gas must be in a high

state of tenuity—so diffuse, in fact, as to be millions of times more rare than any gas we can possibly obtain by experimental physical means.

It was shown that the probable source of energy which excited these tenuous condensations to emit the unknown spectra lines was possibly the intensely hot stars which, according to the Harvard (Draper) stellar classification, are known as the Type "O" (Wolf-Rayet) stars, or the Type "B" (Orion or helium) stars, the temperatures of which may be anything between 35,000° and 100,000° C.

These high-temperature stars are found in close proximity to the nebulae that exhibit nebulium lines; the type "O" sometimes forms the nucleus of the planetary nebulae, while the type "B" is generally connected with the irregular nebulae "without form or void" similar to Orion.

The emission of a certain variety of intense energy from these stars, combined with the wide spacing of the atoms in a nebula, is the cause of the characteristic nebular lines, for the conditions postulated thus allow of relatively forbidden transitions of the satellite electrons of the nebular atoms. As is well known, the atom may be pictured as consisting of a nucleus of positive electrical charge, while to balance the system there are satellite electrons which are charged negatively, the electrons rotating in certain possible orbits round the nucleus. The transition of an electron from one orbit to another is possible. Some transitions, however, are forbidden in the normal state of the atom and are only possible under very special and and stringent conditions. This is termed a *relatively forbidden* transition. When an electron makes a forbidden move, owing, maybe, to the bombardment of the atomic system by a high-speed particle, or radiation from an outside source, it may also radiate energy in the form of light of a certain quality or wave length.

The evidence produced by Bowen indicates then that the N_1 and N_2 lines are due to out-of-the-ordinary electronic movements in a gaseous atom, the gas being *doubly ionized oxygen*, that is, oxygen that has lost two electrons from its normal complement of six. The λ 4363 line is also probably due to oxygen in the same state, while the lines in the ultraviolet may emanate from single ionized oxygen. Still other lines may be attributed to ionized nitrogen. These elements which produce the "nebulium" spectra are the main constituents of our earthly atmosphere, and as Sir Arthur Eddington has so delightfully put it, "The light that never was on land or sea is just common air." Truly, as another writer has said, nebulium itself has vanished into thin air * * *!

The mighty nebulae are very remote from the tiny planet, Earth. But near our home mystery still prevails. Our own star, the Sun,

has its puzzling constituent. Sir Robert Ball, in 1893 (when he was Royal Astronomer of Ireland), said that we have good reason to think that there are two other elements at least in the Sun which are foreign to our terrestrial chemistry. At that time these elements received the provisional names of coronium and helium.

Helium is now a well-known gas. But coronium, the hypothetical element which is a constituent of the solar corona, has not, as yet, definitely yielded up its secret, although there are indications that, like nebulium, it is a well-known gas, or gases, acting in a strange way.

The solar corona is only observed during a total eclipse of the Sun. It is an irregular halo of exquisite and delicate pearl-colored light arrayed round the eclipsed solar disk. Its form varies. Sometimes it is very prominent, whereas at other periods it is weak. It would appear from observations and photographs taken during totality that its general size changes in accordance with the number of sunspots or eruptions that appear on the solar disk. These, as is well known, vary in average number over a cycle of approximately 11 years.

Some observers have noted that the corona form is constantly changing even during the short period of totality, but as a general rule it may be said that when there are the least number of spots on the Sun, the corona is at its largest. During this period of minimum sunspot activity long streamers, or wings, of the corona stretch from the solar equator with lesser streamers or tufts at the poles of the Sun.

This winged shape has given rise to an ingenious theory (suggested first by E. W. Maunder) that the symbol of Ra, the Sun god, a deity of the ancient Egyptians, is an attempt to delineate the shape of the corona. If such is the case these ancients must have been keen observers of eclipse phenomena.

According to various modern authorities who base their theories on spectroscopic observations, the corona consists mostly of gaseous matter with a sprinkling of meteoric or cosmic dust, shining partly by reflected light from the photosphere, and partly by its own intrinsic light.

Spectroscopic observations on the corona are, like those of the nebulae, full of interest. The main characteristic of the spectrum is a very strong line in the green (wave length λ 5303), while other emission lines, some very faint, can also be seen. These lines are superposed upon a relatively weak continuous spectrum which can probably be attributed to the reflected or scattered light from the minute particles near the sun.

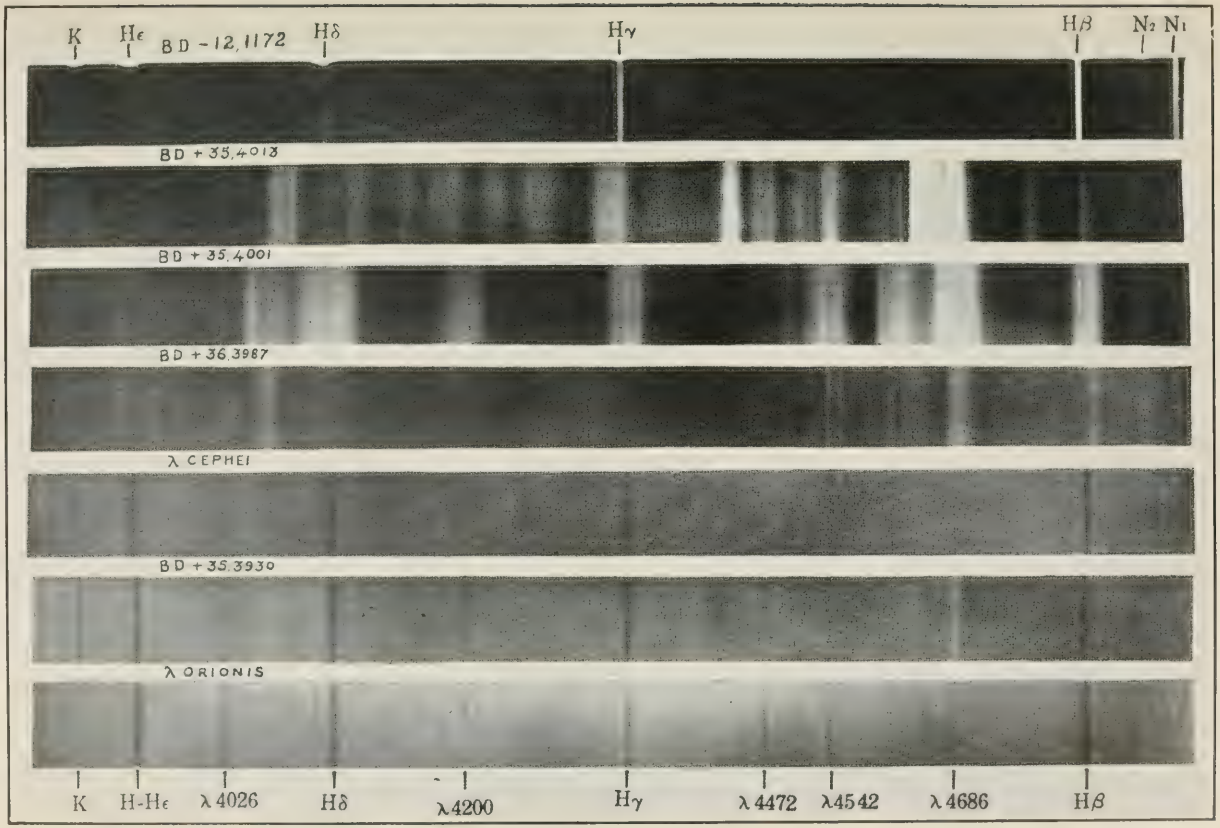
Now the line λ 5303 does not coincide with that of any of the known elements. There has been a suggestion in some quarters,

however, that it may match one of the lines of the aurora borealis. Thus it may well be that there is some connection between the aurora and the corona, for both vary with sunspot activity.

Another prominent corona line in the red has lately been studied closely. It was first discovered during the eclipse of 1914, but it would appear from later observations that it changes its intensity in a marked degree. Most of the corona lines vary somewhat in strength at various periods, as the testimonies of eclipse expeditions indicate. This is what might be expected, for we have already noted how the corona itself changes at sunspot minima and maxima. But the change in the red-line intensity would seem to be greater than the rest. A suggestion has been made that the origin of this line is hydrogen.

Sir Norman Lockyer's statement that coronium was possibly an element lighter than hydrogen cannot be entertained in any circumstances in the face of modern atomic theory. It is impossible for an element to exist that is lighter than the first element in the atomic scale, although the discovery of helium in the Sun (the next lightest element to hydrogen) before it was discovered terrestrially must be attributed to Lockyer.

However, to review the most recent research work, it is possible that coronium may be diffuse oxygen in an unfamiliar ionized state, although this cannot yet be stated with certainty. If such proves to be the case, coronium, like nebulium, will have lost its status as an element of mystery, and the solution of the problem will have gone a long way to suggest that there is nothing new under the canopy of heaven—only change. This postulate is a far-reaching one. Discovery of the future will probably be directed more and more to the proof of this statement.



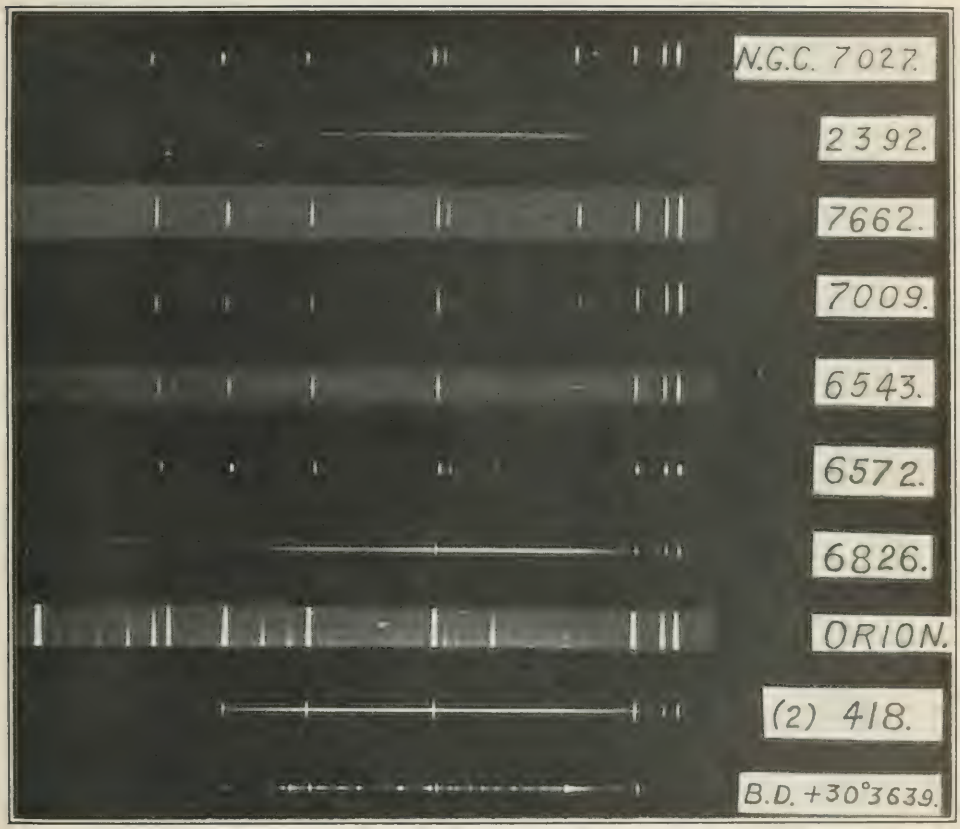
SOME TYPICAL STELLA SPECTRA (CURTISS).

Nebula-class Pa, stella-class O. Note N_2 and N_1 lines.



THE GREAT NEBULA IN ORION, M42, N. G. C., 1976.

Exposure, 3 hours, November 19, 1920. 100-inch reflector. (Mount Wilson Observatory.)



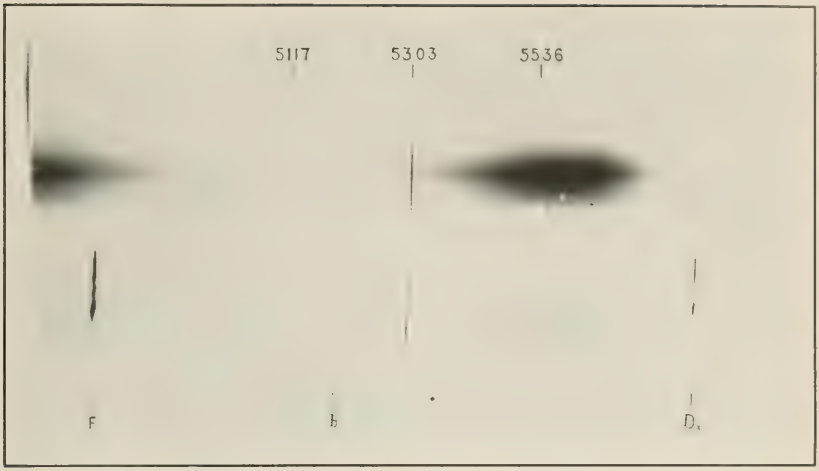
SPECTRA OF NEBULAE.

36-inch reflector. (Lick Observatory.)

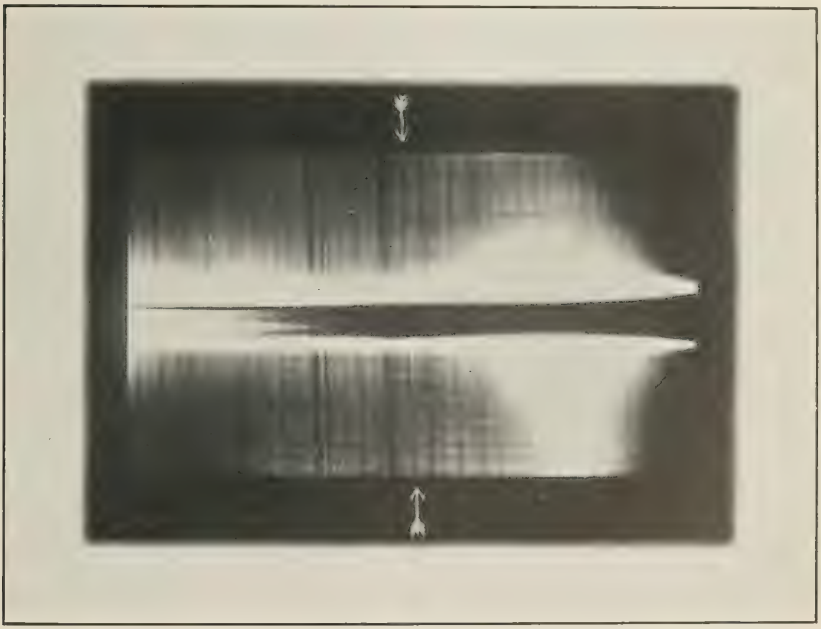


SOLAR CORONA.

June 29, 1927. Jokmokk. (Hamburg Observatory.)



1. SPECTRUM OF CORONA.
August 30, 1905. (Dyson.) Sfax, Tunis.



2. CORONAL LINE 5303 (WITHOUT ECLIPSE).
Exposure, 6 minutes. August 10, 1930. (Lyot.) Pic du Midi

OUR KNOWLEDGE OF ATOMIC NUCLEI[1]

By G. P. Harnwell, Ph. D.

Director of the Laboratory of Physics, University of Pennsylvania

The subject which within the past few years has come to be known as "nuclear physics" is an outgrowth and in many ways the culmination of the research in atomic physics which began with the opening of the present century. You are familiar with many of the practical results of this earlier work, though possibly you do not all realize how directly most of our recent technical developments are due to what at first sight seems like a highly impractical and literally intangible field of investigation. In consequence, I would like first to consider briefly why we study atoms and molecules and what evidence the pure scientist can offer the engineers, who are applied scientists, and also all the other nontechnical members of society to justify their continued support of pure science. For without this support we cannot continue to make fundamental advances in our knowledge of, and control over, our physical environment.

The motivations of the pure scientist would appear to many at first thought as whimsical and abstract as the immediate results he achieves. The briefest explanation of why he works is curiosity rather than the necessity of earning a livelihood. The questions he asks are "Why?" and "How?" rather than "What good will come of all this?" The latter is the first query that occurs to most people and is a question that some of us must answer if the aims and results of pure science are to be widely understood. The gap between these points of view is bridged by realizing that the scientist's aim is fundamentally to gain as wide and deep a knowledge as possible of our physical surroundings. That this alone is a justifiable aim worthy of everyone's support is evident, for the first step toward control over our environment, which results in benefit to all, is a proper understanding of the phenomena and laws of the physical world. Our civilization, excepting our racial biological inheritance, is largely due to the activities of pure scientists. These scientists have not generally

[1] Presented at the Stated Meeting of the Franklin Institute held Wednesday, November 16, 1938. Reprinted by permission from the Journal of the Franklin Institute, vol. 227, No. 4, April 1939.

envisaged the modern applications or developments; this has been the work of engineers and chemists. But without the work of investigators in pure science the engineers would have no knowledge to apply.

That atomic research is the most profitable avenue of investigation of nature and its results the most useful tools for our control over our environment is very clearly brought out by looking briefly at the results that have been achieved. Our first quantitative knowledge of the atomic nature of matter, sketchy and imperfect as it was, can be attributed to Dalton at the beginning of the last century. The laws of the ordered proportions in which elements combine to form compounds pointed unequivocally to this hypothesis. It is from this advance more than any other that the modern science of chemistry is due. Dalton never dreamed of what the modern chemist can do with petroleum, coal tar, and cellulose but without the hypotheses associated with his name and those of his successors we would not have the fuel, power, the means of transportation, or the synthetic materials that make our lives more comfortable, painless, and effective than those of any other age. At this stage of development chemistry begins to branch away from the main trunk of natural philosophy which is physics. The ramifications of chemistry are too numerous for our further consideration, and we shall confine our attention to those results of Dalton's theory that are more immediately related to the later discoveries of atomic research.

The developments of the past century were based largely on hypothesis of the discrete granular structure of matter, but with the beginning of this century we have entered on a more detailed understanding of the properties and characteristics of these atoms in different states of agglomeration and of the actual submicroscopic structure of these material units. The results of these pure scientific investigations have completely changed our material civilization within the past 30 or 40 years. In our homes we have incandescent and glow-discharge lamps, and the latter are merely at the beginning of their development. We have electric heat and artificial sunlight. We have communication with almost every place in the world by telephone, and the radio is an unparalleled disseminator of news and a source of information and entertainment. We have the combination of sound and moving pictures, and television which is still in its infancy. The power and communication industries would not exist as we know them without atomic research. The strength of large structures could not be tested without X-rays, and the electron microscope is just beginning to be applied to metallurgical and biological problems. In medicine atomic research has provided sources of radiation for local heating, X-ray photography and the treatment of disease by the entire spectrum of radiation from the infrared through the ultraviolet to X-rays and radium. This has all occurred

within the spans of our own lives, and none of these things would be available had not the curiosity of such pure scientists as Becquerel, Thomson, Roentgen, Hallwachs, and Richardson been aroused to investigate seemingly trivial phenomena in their laboratories. This is the answer to "What good is research in atomic physics?"

The research of the first quarter of this century may be considered to have laid the groundwork for our investigation of the nucleus or innermost core of the atom. This field is the newest and most fascinating and appears to have the greatest eventual possibilities of future benefit. While something was known of it before the last decade, our first control over these phenomena dates from the work of Rutherford in 1919. Since study implies the possibility of controlling conditions, nuclear research was born in 1919 and took its first steps with the discovery of more powerful techniques by Rutherford's students at the beginning of the present decade. As research on the atomic nucleus is the result of the knowledge we have gained about the external structure of atoms, the methods of attack are fundamentally the same. These techniques themselves are of consuming interest for an inquiring mind because of the difficulty of the problem presented. We are investigating the completely unknown and must free ourselves as far as possible from all prejudices and preconceptions in order to make the most of discoveries as they are made and change our points of view, hypotheses, and methods of investigation to evaluate properly the implications of our data. Atoms themselves are so small that we know we can never see them with our eyes, and their cores or nuclei are as much smaller than atoms as they are themselves smaller than ordinary microscopic objects. None of our senses can ever detect single atoms, but a scientist is not content without the most detailed information about them. And this information must be quantitative and highly precise. When so stated, the problem appears hopeless. That it is not really so is partly due to the ingenuity displayed by the investigators, which represents one of the most remarkable intellectual triumphs imaginable, and partly to the common delusion that all our senses are able to yield us quantitative information and that the more of them we can bring to bear the more complete will be our understanding. Actually, our only precise sense is vision, and in the field of atomic physics it can only be applied indirectly. We must realize at the outset that we will never know how an atom looks, feels, or smells and that such properties as precise shape, sharply localized boundaries, smoothness, hardness, color simply have no significance as atomic attributes.

The question then arises: What can we know and how are we to go about finding it out? One answer is that large-scale visual observations on the motion of microscopic particles which act as

intermediaries between atoms and organisms on our scale provide a method of approach. Also in a few instances it is possible to observe visually the effects produced by very rapidly moving atoms. Our chief quantitative information, however, is received very indirectly but unambiguously through the refined techniques of electrical measurements and consists of a series of pointer readings. The information that we obtained is a rough estimate of atomic size, more accurate information about the forces that hold atoms together and that atoms exert on one another, and very precise information as to atomic masses or weights. The result is that we know atoms are of such a size that about a hundred million of them laid side by side would extend across your finger nail, the smallest weight that you can feel in your hand is a million millions times greater than the force holding two atoms together, and about 24 zeros would have to be written before the figure representing the mass of a thimbleful of water before it would represent the mass of an atom. The determination of an atomic mass is representative of the complex indirect methods of measuring atomic quantities. In the first place, it must be known that an atom can be given an electric charge. Then we must know the magnitude of this charge. We must also have observed that a rapidly moving charged atom is deflected from a straight path into a curved one by a magnetic field. We must have a theory that tells us a relation between the velocity of the atom and an observable quantity such as a voltmeter reading, and one that relates the known charge, radius of curvature, magnetic field, and velocity with the unknown mass. Then from a voltmeter reading, a meter reading giving the magnitude of the magnetic field, and a length measurement that gives us the radius of curvature we are able to measure the atomic mass with an accuracy determined by the least accurate of all the measurements that have gone into a determination of this quantity. In this way we can find the masses of all the different kinds of atoms with an accuracy of about 1 percent. However, relative masses, that is, the ratio of the masses of two different types of atoms, can be determined much more exactly, as these relative measurements can be made to depend, for instance, on the ratio of the two lengths involved in measuring the radii of curvature, and they can be found to 1 part in 100,000. This general fact is true throughout all these types of measurements; absolute measurements in terms of length, mass, and time are difficult to make accurately, but in many instances ratios are of the greatest importance and these can in general be found with much greater precision.

The next question of interest is what structure if any these minute entities possess. In posing this question we must realize that we can never answer it in the detail that we can, for instance, specify the structure of a watch or a locomotive. In the first place we learned

through the work of Sir J. J. Thomson at the beginning of the century that electrons are constituents of all atoms. What is an electron? All we know about it is that there is a characteristic minute invariable electric charge associated with it and that it has an effective mass which is about a two-thousandth that of the hydrogen atom, the lightest one known. Furthermore it acts as if it were a minute electrically charged spinning top for it possesses angular momentum and a magnetic moment. In addition to these facts, we know roughly indeed the volume of space it occupies and that is absolutely all we know about it of this nature. As the electrons associated with an atom represent less than a two-thousandth of the mass of the composite system, practically all of the atomic mass is associated with whatever is left after the electrons are removed. Also, as the electrons have a negative sign by the convention generally adopted and the atom as a whole is neutral, the massive part of the atom must carry a positive charge. Atoms of hydrogen, helium, lithium, and so on up to uranium are distinguished from one another by their properties, which we find are almost entirely determined by the number of electrons they contain. This number is determined by finding how many of them we can remove in the simple cases and less directly for the heavier more complex atoms.

How are the electrons and the more massive constituent or constituents held together to form an atom? As these two components have opposite charges and we know opposite electrical charges attract one another, we have here one possible type of force. Our investigations have shown that there are other types of which we know very little. In the first place the identical nature of the electrons apparently gives rise to forces between them. In addition the spinning or vortical motion that appears to be associated with these elementary particles gives rise to spin forces of interaction in somewhat the same manner as two smoke rings can be bounced from one another. The fact that I cannot describe these forces better shows that we have much to learn about them. But that they necessitate the performance of work to alter an atomic system is clearly established. The amount of work that must be done to produce various changes is something that is very accurately known through our study of the light that can be emitted or absorbed by various types of atoms. For the color, or wave length, of the light emitted by an atom determines directly the energy change taking place. This type of spectroscopic investigation tells us many important things about the electron configuration of an atom from the energy point of view which is the most valuable type of information we can obtain, but nothing of course as to what the atom "looks" like.

We have at our disposal certain bullets or projectiles that travel so rapidly that the ordinary atoms composing matter are relatively at rest with respect to them. One source of these is the natural radio-

active material found in nature, the atoms of which may be described as minute Fourth-of-July sparklers constantly sending out light of very short wave length and also ejecting with high velocities material fragments resulting from their internal disintegration. These fragments have been investigated and found to be of two types. One type is the electron and the other was shown by Rutherford and Royds in 1909 to be the massive portion of the characteristic atoms of the familiar atmospheric gas helium. The electrons are light and easily deflected from their paths, but the helium particles are about 10,000 times as massive and go rending through other atoms in their path leaving great havoc on an atomic scale behind them. A study of the way in which these projectiles are scattered by the atoms of other matter that they encounter was shown by Rutherford to imply very interesting consequences. The electrons associated with these scattering atoms are so light as to deflect the helium particles but little, and the observed angular distribution of the scattered particles implies that the massive portions of the atoms responsible for the scattering are concentrated in very minute regions at the center of the electronic structure of an atom. The diameter of this central mass or nucleus is of the order of a hundred-thousandth the diameter of the atom as a whole. The general relative scale and tenuousness of an atomic system is similar to that of our solar system, where the central sun, though much smaller than the outermost planetary orbit, comprises most of the mass.

These facts and the additional one that radioactive emanations are given off in a statistically predictable way were all that was known of the matter up to 1919. No more was known because no way had been found of affecting the rate or manner of decay of natural radioactive material or of producing any change in ordinary stable atomic nuclei. Without being able to observe directly, or effect any observable alteration, no information could be obtained. The first step in effecting any change in an atomic nucleus was taken by Rutherford in 1919. In this year he observed certain phenomena that could be explained on the hypothesis that he had succeeded in transmuting a nucleus characteristic of nitrogen into one characteristic of oxygen. This simple but epoch-making experiment illustrates one of the techniques early employed in this type of work and also the type of evidence that is obtained and the method of reasoning involved. It is known that when a rapidly moving, relatively massive particle such as an atomic nucleus impinges on certain crystals such as zinc sulphide, for instance, a tiny star of light appears. This is visible to a dark-adapted eye under suitable magnification. These tiny sparks are known as scintillations and indicate the stopping of the atomic projectile in the crystal. Their intensity is not a reliable guide to the exact type of atom stopped

or to its original velocity. A crystal of zinc sulphide scintillates brilliantly in the presence of a bit of radioactive matter owing to its continual bombardment by the helium particles that are emitted by this decaying matter. But if the separation between the radium and the sulphide is increased, the scintillations stop quite abruptly at a critical distance due to the slowing down of the helium particles by collisions with the gas molecules in their path. When the gas in their path was nitrogen, Rutherford found that a few fainter scintillations continued to appear long after the amount of intervening gas was sufficient to stop all the original helium particles emitted by the radium. The faintness of the scintillations indicated that they were produced by a lighter projectile than a helium atom, and the only lighter one known is that of hydrogen. Other confirming experiments showed that these were indeed the cause of the faint scintillations, and still further work showed that they came from the nitrogen and not from any hydrogen impurity. Rutherford then suggested the only plausible explanation, which is that a type of nuclear reaction occurs when a helium nucleus impinges with a sufficient velocity on one of nitrogen and that one of the resulting products is a nucleus of hydrogen, which is generally called a proton. By the fundamental theorem of the conservation of electric charge, the entity left is most likely an atom of oxygen for this has a charge equal to that of the sum of helium and nitrogen minus the single atomic charge carried away by hydrogen.

This was a discovery of the greatest importance which has led to the fascinating developments of nuclear physics in the past 10 or 15 years. The essential correctness of Rutherford's view was verified by Dr. Blackett, who used a beautiful technique due to C. T. R. Wilson. This is a method for rendering visible and photographable the path of one of these atomic projectiles through a gas. From the length of these threadlike tracks and from the apparent density of their image on a photographic plate, and their curvature in magnetic field, the mass, charge, and velocity of the atomic projectile can be determined quite unambiguously. A collision with a nitrogen atom resulting in a disintegration is evidenced by the track of the helium particle from the radium suddenly forking; the long, more tenuous tine represents the path of the hydrogen atom that emerges, and the short, heavy tine is that of the resultant oxygen atom that recoils in accordance with the law of conservation of momentum. Photographs of this type are probably the most informative evidence we have as to what actually takes place at an interaction between nuclei.

Though it was found that many of the lighter atoms could be disintegrated in this way, progress was relatively slow till the advent

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of new discoveries and new techniques 6 or 8 years ago. In 1930 two of Rutherford's students, Cockcroft and Walton, showed that we do not have to depend on the helium particles shot off by radium to produce these effects, but that we can accelerate charged atoms of hydrogen and helium in electric fields until they gain sufficient speed to disintegrate other atoms that they encounter. These particles available in large quantities and with controllable speeds are the chief agents of modern research in this field. The fact that Rutherford's work showed that the law of conservation of momentum is applicable to this submicroscopic world enabled Chadwick, one of his colleagues, to prove in 1932 the existence of a hitherto unsuspected atomic particle with a mass closely the same as that of hydrogen but incapable of acquiring an electric charge. Hence this received the name "neutron." In the same year, at Pasadena, Anderson demonstrated the existence of a new light electronic particle having a characteristic positive charge, the opposite of that of the ordinary electron which had been known for 30 years or so. On the heels of these discoveries progress has been so rapid that I can only indicate briefly our present picture of atomic nuclei and some of the fascinating possibilities that are emerging as a result of these researches.

The fundamental and as yet indivisible particles that have been discovered by research and of which all atoms are probably composed in various proportions are the proton, which is the hydrogen nucleus, and the neutron. When recited baldly, our knowledge of these particles does not seem extensive. We know their masses, which are closely the same, and their electrical characteristics, the proton having a characteristic positive charge and the neutron none at all. We also know very roughly the volume of space they occupy and that they have certain characteristic angular momenta, that is, they behave somewhat like minute spinning tops. As the proton has a charge and is rotating, we would expect it to behave like a small magnet, which indeed it does, and somewhat to our surprise the uncharged neutron also appears to have magnetic properties. This is all we can say about these particles except that there are apparently forces between them that bind them in the characteristic complexes that we know as the nuclei of the atoms of all the different elements. These forces apparently have no analogs in our large-scale world, being of such a short range that they only become evident on an atomic scale, but they are the object of present research and speculation by atomic physicists in many laboratories. When we know more about them, which we can only do by further experimental work, we will be able to understand much more clearly the many

fascinating phenomena that we observe. At present all we know is that they do hold the fundamental particles together in stable groups and these stable configurations represent the nuclei of all the known elements. The simplest is the nucleus of hydrogen, which is the proton itself. Then comes the nucleus of heavy hydrogen, which is composed of one proton and one neutron. The combination of three of these particles appears for some strange reason to be relatively loosely held together or fragile, for we do not observe it in nature, while the helium nucleus which is formed of four, two protons and two neutrons, is a particularly strong and compact structure; so much so that it may even occur as a subunit in building other more complex atomic nuclei. The next lightest atom, that of lithium, is composed of three protons and either three or four neutrons and so on through the entire periodic table till we reach uranium, which is composed of 239 of these units, 92 being protons and the balance neutrons.

A study of the periodic table of the elements reveals many regularities and periodicities among the atomic nuclei. In the early portion of the table protons and neutrons occur in approximately equal numbers in the nuclei but as the atoms become heavier and more complex the laws of nuclear stability, of which we know very little, apparently require that there must be many more neutrons than protons in stable nuclei. We are just beginning to learn something about the forces that hold these complexes together, and in our studies we have been able to make many new kinds of atoms which are not stable but throw off a light fragment or absorb one of their surrounding electrons, thus forming again a stable configuration. The role of the ordinary electron and its positive counterpart is very imperfectly understood, for they appear to be emitted or absorbed by a nucleus, though we have good reason to believe that an electron is quite unsuitable in nature to ever form part of a stable nucleus. Until we have learned more, the mechanism of these processes must remain pure speculation. As the proton and neutron differ characteristically by their charge, the emission of a negative electron may be thought of as the change of a nuclear neutron into a proton accompanied by the simultaneous appearance and ejection of an electron. The emission of a positive electron is the converse process. Small quantities of mass also appear or disappear, but with Einstein's relation between mass and energy we can relate this with the kinetic energy of the ejected particle or the very short wave length electromagnetic radiation that frequently accompanies such a process. This relation ($E=mc^2$), that may be considered either as a consequence of the electromagnetic nature of mass or of the special theory

of relativity, plays a very important role in nuclear theory. It states that there is a simple relation of proportionality between mass and energy. If the kinetic and radition energies emerging from a nucleus are measured, the change in mass can be deduced. This affords a very accurate method of extending accurate mass measurements beyond the region of the lightest atoms into that of the heavier ones where direct comparison methods are relatively inaccurate. There is also the matter of the angular momentum associated with the particles that are ejected by a nucleus. This spin is apparently conserved just as we know it to be in large-scale phenomena, but it still presents many problems to the nuclear physicist.

As a specific example we may consider lithium, which is one of the simplest and lightest elements we know, but one upon which a good deal of work has already been done. For the discussion of nuclear reactions the elements are generally laid out in a two-dimensional chart of which the abscissa is the number of protons or atomic number and the ordinate the number of neutrons in the nucleus. The sum of these coördinates is the total mass number on an arbitrary scale ($O=16$). One type of lithium has three protons and three neutrons—this is the so-called isotope of mass 6—and the other has three protons and four neutrons, the isotope of mass 7. The bombarding particles at our disposal are neutrons, light and heavy hydrogen, and the helium nuclei. We can also shine very short wave length light, which is called gamma radiation, on the nucleus and that may disintegrate it much as ordinary light liberates electrons from a metal plate in the photoelectric effect. When lithium of mass 6 is bombarded by high-velocity protons so that the latter enter the nucleus, the charge and mass number are increased by one unit apiece and beryllium of mass 7 results. This is not one of the known stable atomic species, and we find that a helium nucleus splits off, leaving a residue of mass 3 and charge 2, that is, a heliumlike atom. We do not know this as one of the ordinary atomic species either, and it is likely that some subsequent event occurs to it resulting in heavy hydrogen, though this process has not as yet been observed. One possibility is that the helium nucleus captures one of its two external electrons, decreasing its net charge by one, that is, becoming hydrogen of mass 3. As this is not found in nature either, we are led to assume that it is a very fragile structure which splits up into a neutron and hydrogen of mass 2 upon the slightest provocation.[2]

If the lithium 6 is bombarded by helium nuclei, the neutron

[2] Since the preparation of this article it has been found that helium of mass 3 is stable and hydrogen of mass 3 is unstable, decaying into this light variety of helium.

and proton numbers each increase by two, leading to boron of mass 10. The excess energy left with this nucleus, however, does not allow it to settle down stably, but a neutron emerges which would produce an unknown species of boron of mass 9. This disintegrates by emission of a positive electron into the familiar stable beryllium isotope. If heavy hydrogen is driven at a high speed into a target of lithium, a light and hitherto unknown beryllium of mass 8 would be formed. As we might expect, this is not stable and a proton emerges, leaving the well-known lithium atom of mass 7. It is apparently possible that this lithium atom is not formed in its ordinary configuration but is in a somewhat disorganized state from which it returns to normal with the emission of gamma radiation, for this is observed and can only be attributed to a process of this sort. Finally, if neutrons are used as projectiles, lithium of mass 7 results, but this is not the ordinary stable lithium of mass 7 but again a disorganized type of greater energy. We find that this can settle into a stable configuration in any one of three possible ways. One is by the emission of a gamma ray leaving lithium 7. As we find helium nuclei thrown off, this represents a second mode of distintegration, one product of which is the heavy variety of hydrogen of mass 3. As mentioned previously, this is not found in nature, for it in all likelihood gives off a neutron at some later time and becomes ordinary heavy hydrogen.[2] Finally, the lithium may, however, give off a proton, resulting in another unknown element, helium of mass 6. This exhibits a new phenomenon, for it disintegrates slowly as radioactive atoms do, a neutron changing into a proton, which is evidenced by the external appearance of an electron. The mean life of this type of helium is of the order of a fraction of a second before this shift occurs and lithium of mass 6 again results.

A study of other types of atoms when subjected to bombardment by these heavy-velocity projectiles yields further information of this general type but with the appearance in certain instances of positive electrons and other less well understood phenomena. Also, if our ideas are correct, the incidence of gamma rays on lithium of mass 7 should result in the emission of a neutron and the production of lithium of mass 6. As yet a suitable source of gamma rays is not available to test this hypothesis. This simple discussion of nuclear phenomena by means of our diagram resembles to some extent a type of chess. One has certain squares representing stable elements from which we must begin and on which we must probably end. The possible initial moves are determined by the type of projectile, for if electric charge and large units of mass are conserved,

[2] Since the preparation of this article it has been found that helium of mass 3 is stable and hydrogen of mass 3 is unstable, decaying into this light variety of helium.

the end of the first move has coordinates determined by the sum of all the protons and neutrons involved. The second move depends on the element which is formed and the state of disorganization in which it is left. We have observed helium nuclei, protons, and neutrons to be emitted in various instances and also both positive and negative electrons, probably evidencing a proton-neutron or neutron-proton conversion within. In some instances we have observed two successive processes, but in these one or two moves the process completes itself and we are back on one of our permitted squares representing a known stable element. From observations on the energy put in or liberated in its various forms of motion, mass, and radiation we have learned something more than I have been able to tell you of nuclear mechanics. But it is still essentially a great unexplored field which is rich in scientific possibilities.

We have seen that research in atomic physics has amply justified itself to society by its important applications which have almost remade our technical civilization. We might ask whether the field of nuclear physics has any such potentialities. The answer is undoubtedly in the affirmative, though it would indeed be a rash prophet who would undertake to state exactly what developments may be expected. It is impossible to tell how soon our knowledge of, and control over, these nuclear processes will have any reaction on our everyday life, but the processes of technical development and dissemination are apt to be even more rapid than in the case of atomic physics. We can only consider here one or two of the possibilities that are at present being tentatively explored. In the first place the possibility of obtaining power from the nucleus is not entirely visionary. With our present techniques the process is very inefficient, though great strides have already been made in this direction. Furthermore, this power is of a highly specialized kind and will require as yet undeveloped engines for its utilization. In the second place the neutron which is a little-known entity may be either directly or indirectly of biological significance. Its direct effect on tissue and its various constituents will certainly differ from that of X-radiation for instance, but it is too soon to say just what its effects will be and in what instances they will prove beneficial.

The possibility of making a small fraction of the atoms of almost any substance radioactive is a development with unbounded potentialities, and many interesting applications have already been made. The direct therapeutic effects of the radioactive variants of ordinary elements are the same as those of radium, and if there were no other result than the production of large amounts of equivalent radium, it would be one of the most important discoveries ever made. The fact

that atoms can be endowed with this radioactive property without losing their ordinary chemical properties makes the work of much greater importance than the discovery of any amount of radium would be. As a single instance the thyroid gland is known to have the property of assimilating iodine. It is possible to render iodine radioactive in such a way that it decays with a mean life of about 25 minutes with the emission of ordinary electrons. Thus radioactive iodine injected into the body will tend to be localized in the thyroid gland and affect it specifically in a way not possible with ordinary radium. Also the atom resulting from the emission of the electron is no longer radioactive and peculiarly inert chemically, which removes any possible hazard of the treatment. In a similar way phosphorus and calcium which are bone constituents may be rendered radioactive, localizing radioactive material in the bony structure.

The applications in the closely associated field of physiology are of equally great interest. As it is easy to detect the presence of a very minute number of radioactive atoms among a great number of the ordinary variety characteristic of the element, it is possible to prepare samples of elements that retain their identity and may be followed through physiological reactions. It has been reported, though not as yet verified, that long-lived radioactive carbon atoms can be prepared. These may form molecules of organic compounds which can then be followed through the body, opening up a new and highly important field of biological research. The physiologist can investigate the details of processes for which no technique was previously available, and hitherto unsuspected phenomena may be uncovered. As an instance it is known that the thyroid assimilates iodine, but if other glands assimilate selectively specific elements they do it in such small quantities as to be undetectable at present. However, if the elements were introduced in a radioactive form, simple and powerful techniques of detection could be employed which would bring any selective assimilation to light.

I can only refer even more briefly to the application of this technique in other fields. Radioactive "tracer atoms" can be employed in chemistry to follow chemical elements through exchange reactions. They may also be used to investigate the baffling problems of catalyst poisoning and surface adsorption. In metallurgy and the physics of solids they may be used to study the diffusion of atoms through single crystals and across and along crystal boundaries. Studies of this sort under various conditions of temperature and strain should clarify many of the problems that are now presented by the solid state and lead to alloys with more desirable properties for all the various applications. Applications to many

other fields of science and also to industry suggest themselves immediately, though our time is too short to consider them. If nothing emerged from nuclear studies but this one technique, I doubt if the present equipment in all the laboratories in this country would be adequate to supply the radioactive material for the applications that will develop within the next few years. We are undertaking this type of work at the University of Pennsylvania to the extent that our rather limited funds permit, and we are convinced that this vast unknown field has even more important possibilities in store for us. We hope that we shall be able to interest sufficient support not only to contribute this technique to physics and our sister sciences, but to go on and explore the very promising field of the nucleus with every confidence that the understanding gained thereby will lead to still more important developments in the future.

SPECTROSCOPY IN INDUSTRY[1]

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[With 4 plates]

The spectroscope, long recognized as one of the most powerful tools of scientific investigation, has been used during the past 40 years to obtain information which has revolutionized physics, chemistry, and astronomy, and greatly affected biology, metallurgy, and medicine. Since many modern industries rest on scientific discoveries in these fields, it would be surprising if the spectroscope were not found useful in connection with technological processes. So rapidly, in fact, are spectroscopic methods now being adopted by industrial laboratories, that most manufacturers of spectroscopic equipment are having difficulty in keeping up with orders for their instruments, and some are even beginning to worry about the availability of such raw materials as crystal quartz, needed for prisms and other optical parts. Spectroscopic methods have been found particularly valuable in the metals industries, in those industries which involve the canning and packaging of foods, and in all other industries which use materials whose purity must be carefully determined and controlled.

The spectroscope has served the physicist and the astronomer as a telescope, a microscope, a speedometer, a thermometer, a tape measure, and a clock, in addition to its more usual functions; and in each role it has exceeded in range and power the more common forms of these devices. Today in industry its greatest usefulness is found in applications which supplement chemical wet methods of qualitative and quantitative analysis, and with its aid our ability to detect and measure small quantities of material has been extended very greatly.

As has often been pointed out, a teaspoonful of salt cannot hide from a spectroscope in a swimming pool full of water. Though far less gold than would repay concentration is found in sea water, the spectroscope has no difficulty in detecting the small amount which

[1] Presented at a meeting of The Franklin Institute held Thursday, February 3, 1938. Reprinted by permission from the Journal of the Franklin Institute, vol. 226, No. 1, July 1938.

is there. Such sensitivity might appear excessive for industrial purposes, where ability to detect a trace of almost any element in any given sample would seem valueless if nothing could be done about its presence. Fortunately, something usually can be done. Though in many cases the properties of metals are greatly influenced by traces of impurities too minute to be eliminated conveniently by ordinary methods of purification, addition of minute quantities of other impurities will often offset undesired characteristics. In the case of fusible alloys for safety valves or fire sprinklers, for example, certain impurities if present by as much as 1 part in 10,000 will raise the melting point by undesirable amounts. A relatively small number of atoms in the crystal boundaries can produce a marked effect, but atoms of other materials which will depress the melting point again to its proper value can be added. The spectroscope is invaluable in determining which impurities are responsible for such effects, and which elements must be added to offset them.

The outstanding value of the spectrograph comes in qualitative analysis. Let us watch two scientists looking at a tiny piece of lamp filament. To all outward appearances it is exactly the same as any other piece of filament, but in an incandescent lamp it was found to last twice as long as did filaments made from ordinary wire. There is not enough material to analyze chemically, for the sample is small and no advance hint tells what to look for. A chemist using ordinary methods would be forced to guess as to which elements were most probably present, and eliminate them one after another. Long before he was finished such a small sample would probably be exhausted. But here is a spectrograph; the operator loads it with a photographic plate, opens the shutter, and inserts a tiny piece of the filament into an electric arc placed in front of the instrument. There is a flash of colored light and the spectrum is recorded. Shifting the plate the operator repeats the process, the second time burning a piece of an ordinary filament. When he develops the spectrogram the story stands completely revealed. Each type of atom in each filament has sent out its own group of waves of different lengths, and produced its own pattern of spectrum lines. By looking for differences in these patterns, and identifying the elements from which the various lines which differ are known to originate, the spectroscopist can see quickly and accurately which elements are present in one filament and not in the other.

The pattern of lines on a spectrum photograph may look complicated and meaningless to the layman, but to the experienced spectroscopist it often tells a story as definite as that told by a line of printing. This was perhaps not realized by the advertising agents of a manufacturer of motorcars who recently strove to impress the

American public with the scientific methods used in his factory, by printing in some of the leading weeklies full-page advertisements which pictured a laboratory worker gazing at a spectrogram, with the caption "Eyes That See Through Steel." The description which followed of the value of the spectroscope in perfecting automobile parts was a very good one, but every line in the spectrum at which the man was looking quite obviously had come from zinc atoms!

Spectroscopic analysis indicates that no entirely pure sample of any metal has ever been prepared, and since single foreign atoms placed here and there in the lattice structure of a metallic crystal can greatly affect its properties, really pure metals probably have properties with which we are as yet not familiar.

In the food-preserving industries the spectrograph is coming into very wide application. That 2 or 3 parts of aluminum or lead can be detected readily in 10 million parts of lobster or condensed milk may seem unimportant, since such concentrations are below the toxic limits considered dangerous to health, yet obviously tests on the rapidity with which the internal coatings of cans dissolve in foods stored within them can be made more easily and quickly when such sensitive methods of detection are available. Chocolate and chewing-gum manufacturers use spectroscopic analysis to insure that the lead content of their products is below the limits set by pure-food laws. Whiskey distillers, finding something in their product which causes it to turn cloudy, have used the spectrograph to locate the cause in minute amounts of cadmium, let us say (to cloak the real offender in anonymity); and by analyzing samples from various parts of the distillery line, have been enabled to locate the coil or condenser which introduced the offending element.

Has the arsenic and lead been properly removed from sprayed fruits before canning? The spectrograph will tell. Is beer kept in cans dissolving anything more from the container than it would if kept in bottles? Again, the spectrograph gives an easy means of deciding.

Spectroscopic analyses can be performed by two entirely indepedent and dissimilar means, which have different applications. In emission analysis, use is made of the characteristic light emitted when the material is burned electrically in front of the slit of a spectrograph. In the second method, absorption spectrophotometry, light waves of every length in the desired region are sent through the material to be analyzed (which must be somewhat transparent, like glass or blood serum or peppermint extract or beer) and the spectrograph is used to determine how much of the light of each wave length has been absorbed by the material.

By the first method, 70 of the chemical elements can readily be detected and measured. The permanent gases, carbon, and a few other nonmetallic elements produce few lines in the spectral regions commonly photographed, and since almost all molecules are dissociated in the arc into their constitutent atoms, organic materials are burned away without appearing in the analysis. When an apple or a cranberry is ashed in an electric arc, for example, the strongest lines which appear in the spectrum are those due to such elements as sodium and copper and iron.

When one is interested in molecules, the second method of spectrographic analysis can be used. Though its application is limited to materials which are somewhat transparent, it has the advantage of not affecting the material which is being analyzed, since this is merely penetrated by a beam of light.

The modern spectroscope is not the small brass tube standing on a tripod so familiar to chemistry students, who have used it to observe the colored lines produced by different salts when burned in a flame. One of the research instruments used for precise work may fill a room 40 feet square (as shown in pl. 1), and several laboratories contain more than a dozen different types of spectrographs. For industrial work three main types are in most common use. The quartz prism instrument of medium size, which records on one plate the spectrum between the limits 5000 angstroms and 2000 angstroms, is useful for absorption spectrophotometry, since the absorption bands of solids or liquids are usually so wide that great separation of the waves of different lengths is valueless. This instrument can also be used for emission analysis where the substances being studied have fairly simple spectra, such as the alkalies and alkaline earths, and in general those atoms which lie on the left-hand side of the periodic table. Iron and most other atoms of the long periods have such complex spectra that greater resolution of the lines is required, and a large quartz instrument of the Littrow type is most commonly used. This records in 3 settings the part of the spectrum most important for analytical purposes, lying between 2000 angstroms and 5000 angstroms, when a quartz prism is used, and a glass prism can be substituted with which the visible spectrum can also be recorded.

The concave diffraction grating spectrograph has long been considered one of the more convenient types of spectrograph in research laboratories, and this instrument is now slowly making its way into industrial use. It has the advantage that it can be used with light waves of any length from the long infrared to the shortest ultraviolet, a single instrument covering all the desired ranges without change of optical parts. Again, the grating produces almost uniform dispersion from the shortest to the longest wave lengths, whereas the dispersion of a prism decreases rapidly toward longer wave

length, which makes identification of the lines easier and uses the photographic plate more effectively. The new aluminum gratings on glass, ruled by R. W. Wood at Johns Hopkins, have done much to remove prejudice against the grating because of the comparatively low intensity of the spectra it produces. Several of Wood's gratings produce spectra more intense than those produced by prisms, and with such a grating exposures in which thousands of lines from an iron arc are recorded in 5 seconds are not uncommon.

Some industrial users of spectographs who express great satisfaction with their prism instruments consider the grating spectrograph too fragile for use in their laboratories. This speaks well for the prism type of instrument, but usually bespeaks lack of familiarity with the grating. Where good prism and grating instruments are both available, the grating instrument is commonly the favorite, and that it cannot be the delicate apparatus sometimes supposed is borne out by its very satisfactory use in such metallurgical laboratories as those of the Watertown Arsenal and the Cleveland Lamp Works.

As a typical example of all-around use of the spectrograph in attacking an industrial problem, I shall discuss the spectroscopic procedure connected with what we may call "The Case of the Hafnium Crystals." (The real crystals were not hafnium, nor were they, in fact, crystals.) The spectroscopic procedure used was so varied that the case serves as an excellent illustration. The problem was to locate minute deposits of hafnium in a certain transparent crystalline mineral and to measure the distribution and amount of the hafnium in typical crystals. The spectrographic method was selected as one of the best ways of doing this.

First, emission analysis was used to determine the amount of hafnium present in the crystal material. Several milligrams of the material were burned in an electric arc, and the light emitted was photographed with a spectrograph. The wave lengths of all lines appearing on the plate were then determined with an accurate measuring engine, and from published catalogs of wave lengths all lines appearing on the plate were assigned to their parent atoms. A qualitative analysis of all metallic elements present in amounts greater than about one part in a million was thus obtained.

A spectrographic quantitative analysis was next made. From the qualitative analysis the elements could be grouped into three classes by observing the intensities of their spectrum lines. Those which were present in large concentrations (above about 1 percent) were listed as major constituents, those present in amounts lying between 1 and 0.001 percent were listed as minor constituents, and those present in smaller amounts as traces.

In general, one may say that for major constituents, spectroscopic methods of quantitative analysis are slightly inferior in precision to chemical wet methods, for minor constituents they are equal in precision, and for traces they are superior, assuming sufficiently large samples are available to make adequate chemical analyses. Spectroscopic methods have their greatest advantage when the samples available are small, or concentrations are low, because the precision of the spectroscopic method stays sensibly constant at all concentrations. With it one can distinguish as readily between 0.0010 and 0.0011 percent concentration of material as between 10 and 11 percent, for example.

The concentration of a minor constituent is determined by observation of the intensisties of its spectrum lines relative to those of the matrix material (which is composed of the major constituents), and as these ratios vary with a number of factors, a null method must be used. Standard comparison samples are made up which differ from the sample to be measured only in regard to the contituents being measured, and these samples and this unknown are burned and photographed in identical manner. Then, if the intensities of the line of the constituent in question are the same in any comparison sample as in the unknown sample, the concentration of the constituent will be the same in the two samples.

Such rigid conditions might seem impossible to fulfill, but fortunately any number of minor constituents and traces may differ in the known and unknown samples without affecting the result. If we are comparing the copper content of two bronzes, for example, error may result if lead be present in one sample in amounts greater than 1 percent, and not in the other, but in amounts less than about 1 percent a difference in lead content should not affect the results appreciably.

Returning to the crystal problem, having made up a series of samples of the material containing various known concentrations of hafnium covering the range suggested by the qualitative analysis, we now burn these in the arc in succession, sandwiched between alternate exposures burning the unknown sample. When the plate has been developed, fixed, and dried, we can measure the amount of blackening of each of the hafnium lines on a microdensitometer, and plot a "working curve" of density against concentration. Or, as is more common, by calibrating the plates we can change densities into the actual line intensities to which they correspond, and plot $\log_{10}$ intensity against $\log_{10}$ concentration. At low concentrations such a plot is usually a straight line (as shown in fig. 1), which aids greatly in interpolating between two standard intensities. By this means, using care, precision to 3 percent can usually be obtained, which at

concentrations below 0.1 percent is ordinarily greater than that of chemical methods.

Having determined the actual amount of hafnium present, we are now ready to determine its location in the crystals. The first method tried was to pick out small particles of the crystal and burn them in the arc, observing visually the intensities of the visible hafnium lines with a spectroscope. A sample the size of a pinhead was found to

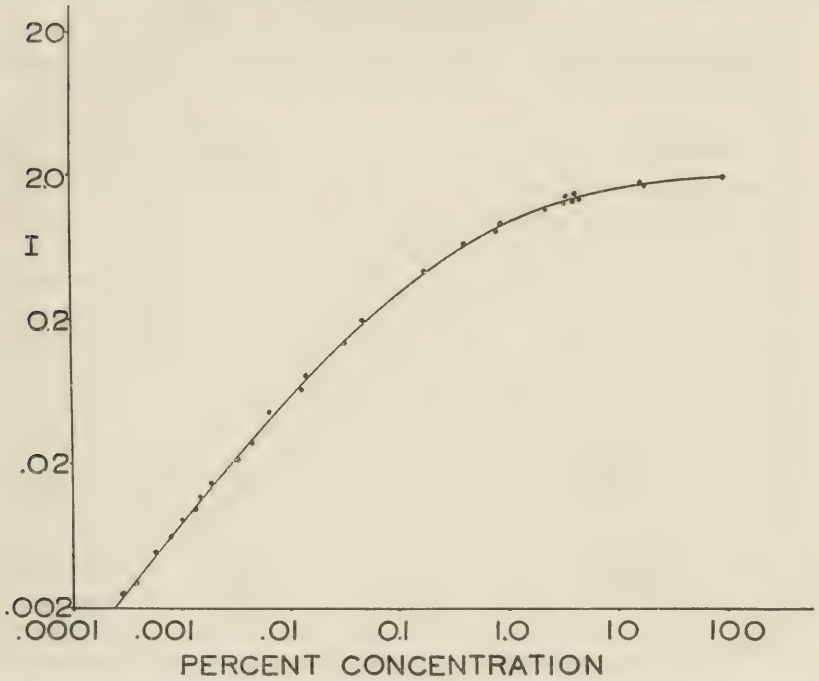


FIGURE 1.—A typical working-curve, for determining the concentration of an element present in a sample burned in the electric arc, in terms of the intensity of one of its spectrum lines photographed under standard conditions. The logarithm of the percent concentration of the element is plotted against the logarithm of the intensity of the line, as determined from a number of samples of known concentration. At low concentrations the curve is theoretically a straight line having 45° slope, which greatly simplifies quantitative spectrographic analysis at low concentrations.

give fairly consistent results, but particles less than 1 mm. in diameter were too likely to be lost from the arc. A series of runs was made to determine the minimum amount of hafnium which could be detected spectroscopically. A weighed sample of the material, known to contain 10^{-5} gm. of hafnium, was introduced into a 2-amp. arc between pure graphite electrodes. Strong hafnium lines were found to be still visible in the spectroscope after 1,000 seconds of burning. The spectrum was then photographed with a high-speed spectrograph, and an exposure of 0.0001 seconds was found sufficient to record the

lines. This indicates that no more than 10^{-12} gm. of hafnium were required for spectrographic detection, but actually the efficiency of excitation of the hafnium atoms is much greater under these conditions than under conditions in which only the minimum detectable amount of material is introduced into the arc. 10^{-8} gm. can usually be detected without difficulty, however.

Emission methods were thus shown to be insufficiently sensitive for the problem at hand. Since the crystals were transparent, the absorption method could be tried, and this method was found satisfactory. Ultimately, amounts down to 10^{-18} gm. of hafnium were successfully located in the crystals by absorption methods.

The first step in this new attack was to determine the absorption spectrum of hafnium salts of the type present in the crystal. The hafnium-containing crystalline material was dissolved in water, and a quartz vessel filled with the resulting solution was placed between the light source (a hydrogen discharge tube, which gives a good continuous spectrum in the ultraviolet) and the slit of the spectrograph. On the same plate an absorption spectrogram was taken of similar crystal material which contained no hafnium, as shown in plate 2, figure 2. The differences in absorption were obviously due to the hafnium salt, which was found to absorb strongly in the ultraviolet, a little in the violet, and practically not at all in the visible region.

The final step was to locate spots in the crystals which showed this characteristic absorption. For this purpose a spectrograph and an ultraviolet-transmitting microscope were combined. Sections of the crystal were thus photographed in each individual line of the mercury spectrum from a quartz mercury arc. Thus the crystal was photographed under high magnification in transmitted monochromatic green light, in blue light, in violet light, and in the light of several ultraviolet lines.

Opaque materials in the crystal showed dark in all these photographs. Transparent materials which were not hafnium showed light in all, as in plate 3, figure 1, where each bow contains a separate photograph. The hafnium salts showed transparent in green and blue light, darker in the violet light, and opaque in the ultraviolet, as in plate 3, figure 2. Thus any particle which showed this progressive absorption could definitely be called a hafnium carrier, and from its opacity its hafnium concentration could be determined.

This method was then further simplified by using a microscope adapted to either visible or ultraviolet light, and taking duplicate photographs of each crystalline particle, immersed in an oil of the proper index of refraction, first with green light as in plate 4, figure 1 (left), and then with ultraviolet light of the desired wave length, as

in plate 4, figure 1 (right). Magnifications up to 2,000 diameters could be used, and thus extremely small amounts of hafnium could be located, since a layer of "hafnium" atoms only 5 atoms thick will give an observable degree of opacity.

Most industrial spectroscopic problems are simpler and more readily solved than the one sketched above, but it is described as illustrating a number of different methods of using a spectrograph.

For many industrial purposes it is important that speed be combined with precision. Two hundred tons of molten copper in a furnace represents a large investment which can be lost through improper treatment. The copper must be removed from the furnace at the proper degree of purification, and several hours may be consumed in determining by chemical methods the proper time for removal. Often recourse is had to rule-of-thumb methods, for lack of anything better. An ideal solution would be a spectroscopic arrangement such that the furnace operator could periodically dip some molten copper from the furnace, burn it before a spectroscope and decide from the appearance of certain impurity lines exactly when the proper time for removal was reached. There is no fundamental reason why this operation should take more than 2 minutes if performed visually or with a photoelectric cell.

Eye methods can be used in certain cases only, since many of the important lines for analysis lie in the ultraviolet region. It is, to be sure, possible to use fluorescence to observe ultraviolet lines, but this method has not yet been well developed. It awaits an increased demand from industry, which in turn awaits knowledge of the feasibility of such methods.

The photoelectric method of spectroscopic analysis has been tried with encouraging results in Germany and at the Watertown Arsenal in this country and shows considerable promise, though it must be considered as in only a preliminary state of development. The limitation on this technique, which is simple and should be capable of precision, is in getting enough light to operate photocells from a single line of an element which is present in the sample in only small amounts, when this line is in the midst of a bewildering array of strong lines from other elements. Spectroscopes of high speed, combined with improved phototubes and amplifiers, and improved sources will probably bring ultimate perfection of this rapid method.

The photographic method can be speeded up greatly, and in at least one foundry, that of the Campbell, Wyant & Cannon Co., of Muskegon, Mich., most of the routine chemical tests on the output of the foundry have been superseded by rapid spectrographic methods.

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Quick results are of great importance, and by hastening the processing of the photographic plates used a method has been developed which gives precise quantitative analyses on 6 elements in a single sample in 15 minutes or less. As reported by Vincent and Sawyer,[2] spectra for 48 analyses on 8 samples are recorded on each plate, and the posting of results from a plate can be completed within 35 minutes after receipt of the samples. Repeat runs were found to be more consistent from the spectrographic laboratory than from the chemical laboratory for such elements as silicon, molybdenum, chromium, nickel, manganese, and copper.

Such successful utilization of the spectograph 20 hours a day in a foundry under industrial conditions of stress, with resulting improvement in precision of results, speed, and decrease in cost, emphasizes that the spectrograph is a practical tool.

For rapid testing of raw materials special simple types of spectroscopes have been developed by various manufacturers. A notable example is the Spekker Steeloscope of Adam Hilger, Ltd. This is a small portable fixed-prism spectroscope with a movable eyepiece on which are engraved the various important lines of elements which are to be sought after. A technician of moderate skill, who needs only a reasonable amount of special training, can travel from one car to another of a freight train loaded, for example, with pig iron, carrying his spectroscope and dragging behind him a 220-volt cable carrying direct current to run an electric arc. Selecting a sample pig he strikes an arc between this and a rod of pure iron which he carries for the purpose, and observes the light through his spectroscope, with the eyepiece set for "nickel" or whatever element he is interested in. A special eyepiece can be obtained which, by a clever optical arrangement, enables the eye to compare the intensities of two lines. By setting this at some predetermined value the operator is enabled to tell at once whether the nickel content, for example, is within the limits of acceptance, and it is thus a job of but a few hours to sample and analyze a whole trainload of iron without even bothering to unload it.

Such possibilities in industry are almost endless, but since special methods are required for special purposes, their application awaits the demands of industrialists. The first reaction to the spectroscope is usually amazement at its possibilities. Somewhat further investigation then frequently brings a reaction of disappointment, because it will not solve every problem which may be presented. The next reaction is that perhaps matters are not so hopeless after all, since a little special attention to each case may show how to get around the difficulty.

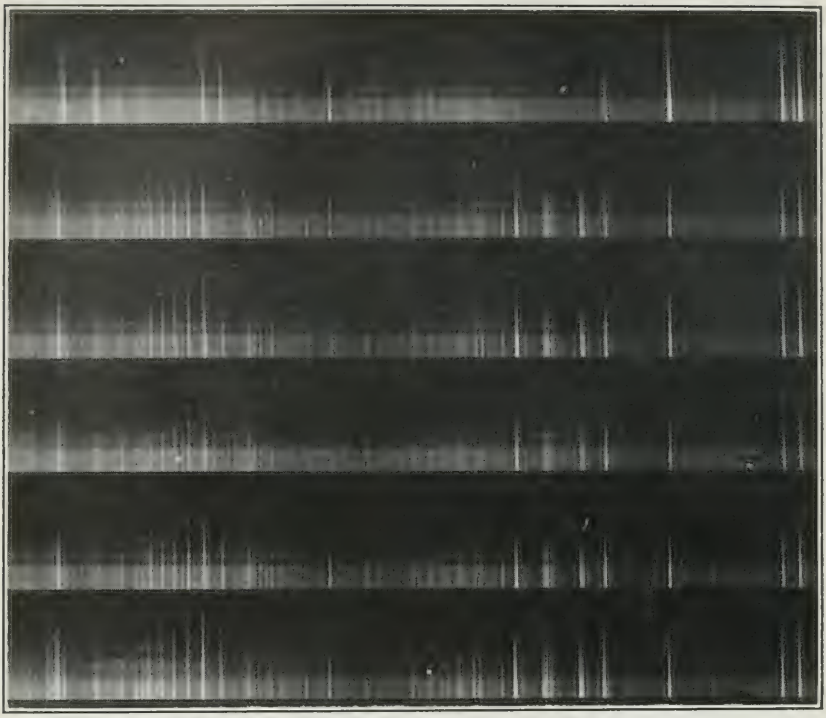
[2] Vincent, H. B., and Sawyer, R. A., Journ. Appl. Phys., March 1937, p. 163.

So we see paper manufacturers who want to discover the scource of tiny black specks in their product, bakery equipment manufacturers who wonder if their new coating compound for pans is contaminating the dough, spark plug manufacturers who wish to study the effect of minute amounts of alkali metals in improving sparking, metallurgists who wish to trace the origins of ores, all trying spectroscopic methods, and usually finding them helpful. It should be remembered that application of such methods to industry is only beginning, and their full power can only be realized by detailed attention to such problems as are presented for solution.



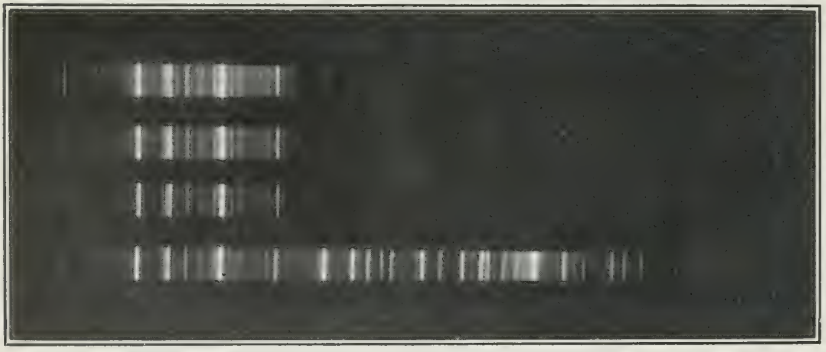
SECTION OF A LARGE CONCAVE GRATING SPECTROGRAPH AT THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY, WHICH COVERS OVER 1,200 SQUARE FEET OF FLOOR SPACE.

The spectrum lines are photographed with high precision on 40 feet of photographic plates clamped to the tracks shown.



1. TYPICAL PORTIONS OF SPECTROGRAMS TAKEN IN ONE TYPE OF QUANTITATIVE SPECTROGRAPHIC ANALYSIS.

In this method each line is photographed in such a way that it decreases in intensity along its length.



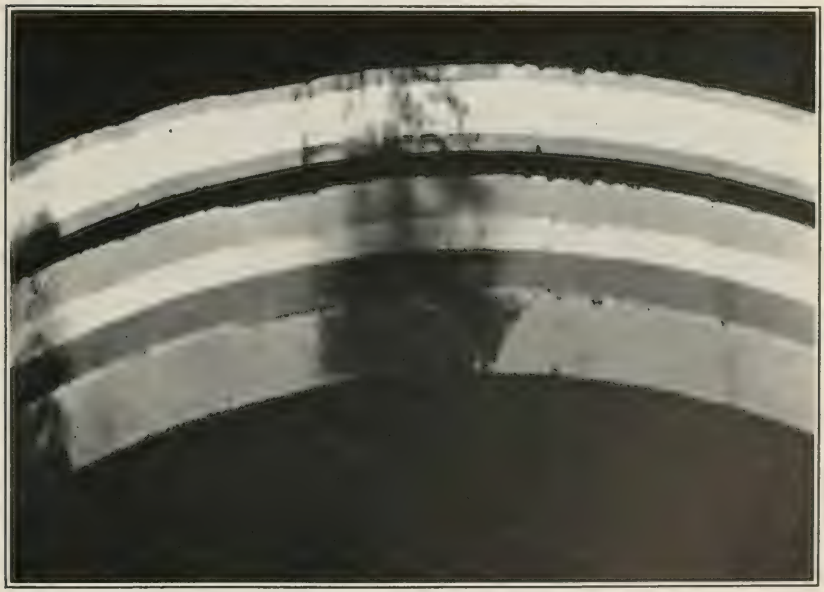
2. TYPICAL ABSORPTION SPECTROGRAM.

The long lower spectrum is of the unabsorbed light; the three upper spectra were taken with some of the "hafnium crystals" in the light beam, and show transparency in the green, beginning absorption in the blue and violet regions, and opacity in the ultraviolet.



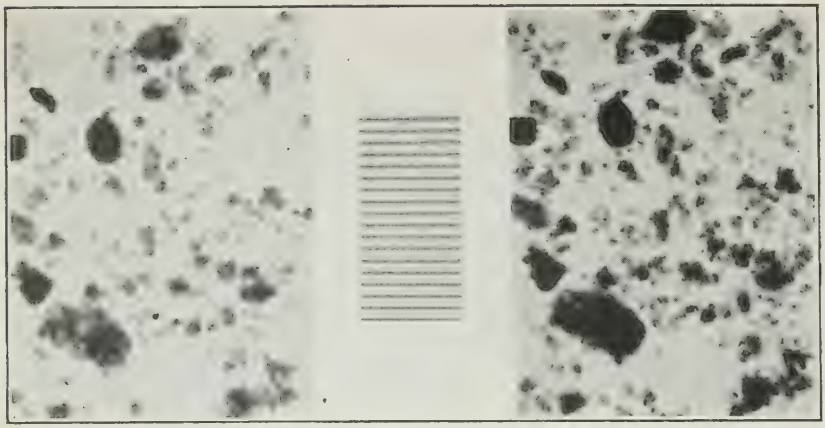
1. "RAINBOW SPECTRUM" OF CRYSTALS CONTAINING HAFNIUM SALTS, TAKEN WITH A MICROSCOPE AND SPECTROGRAPH IN COMBINATION.

Each "bow" is a spectrum line of a given color, and the same microscopic region is photographed in each color. The lower bow is an ultraviolet line, the upper bows are visible lines.



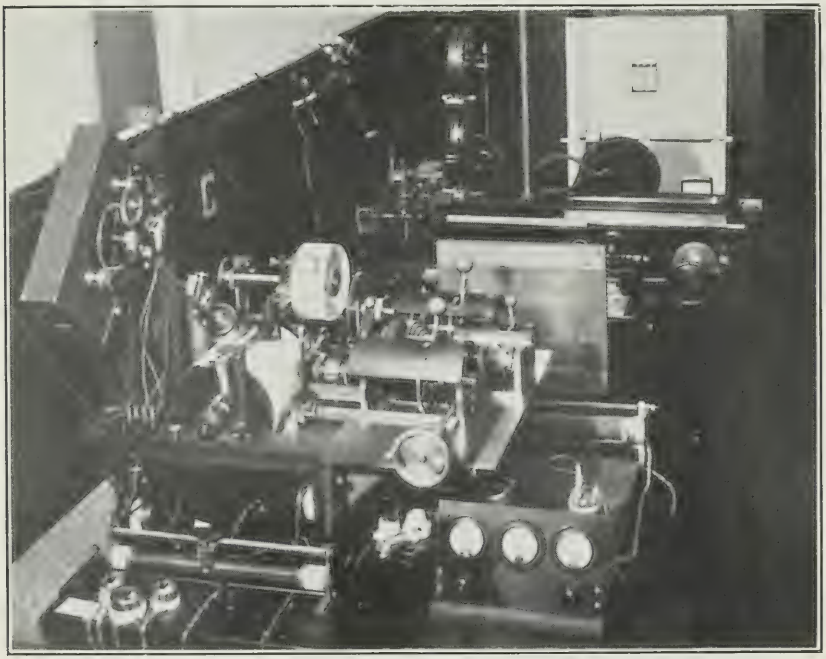
2. SAME TYPE OF SPECTROMICROGRAM AS IN FIG. 1 (ABOVE), BUT WITH HAFNIUM-CONTAINING CRYSTALS IN THE FIELD.

Note the darkening produced by absorption of ultraviolet light by the hafnium crystals in the lower bows and the relative transparency of the hafnium in the upper bows.



1. PHOTOMICROGRAMS TAKEN OF HAFNIUM CRYSTALS IMMERSED IN TURPENTINE (LEFT) TAKEN WITH GREEN LIGHT, AND (RIGHT) WITH ULTRAVIOLET LIGHT.

Any particle appearing transparent in photomicrogram at left and opaque in one at right contains hafnium.



2. AUTOMATIC MACHINE FOR MEASURING, COMPUTING, AND RECORDING THE WAVE LENGTHS OF SPECTRUM LINES, WHICH HAS SPEEDED UP THESE OPERATIONS SOME 200 TIMES

Over 8 million measurements have recently been made at the Massachusetts Institute of Technology with this machine and an improved model, and it is expected that a new catalog of wave lengths of spectrum lines containing the results will soon be issued. Such a set of tables is badly needed, as the last systematic set of measurements of this sort was made in 1911, and greatly improved methods are now available.

PHYSICAL SCIENCE IN THE CRIME-DETECTION LABORATORY [1]

By J. Edgar Hoover

Director, Federal Bureau of Investigation, U. S. Department of Justice

[With 5 plates]

During the latter part of 1937 a police department in one of the eastern States, in submitting to the Federal Bureau of Investigation for laboratory examination a pocketknife and telephone cord, advised that the telephone cord had been severed by a burglar in an effort to delay notification of the authorities of the crime, and that the pocketknife had been recovered in the possession of a suspect apprehended during the subsequent investigation. In addition to the examination of other evidence forwarded at the same time, the police department requested that an effort be made to ascertain whether the suspected pocketknife had in fact been used to cut the telephone cord.

Under the microscope there were observed on the cutting edge of the knife blade minute bronze-colored stains. These stains were far too small to permit their ready removal and identification by routine chemical analytical methods. However, a spectrographic examination of the cutting edge of the knife blade revealed the presence thereon of the two chemical elements, copper and tin, which elements were found by a similar examination of the back edge of the knife blade to be elements not a part of the blade material itself. Inasmuch as a spectrographic analysis of the telephone cord indicated that copper and tin were the principal constituents of the severed conductor, this information was immediately furnished to the contributing agency for use in its further investigation and prosecution of the matter.

During the early part of 1938 an examiner from the Bureau's technical laboratory testified relative to his findings in the matter before a court hearing the evidence against the suspect, as a result of which, together with other evidence introduced at the trial, the suspect was found guilty of the burglary and sentenced to a penitentiary for a period of from 5 to 10 years.

The above case illustrates, probably better than any other proof which might be brought forward, the profoundly important part

[1] Reprinted by permission from The Review of Scientific Instruments, vol. 9, No. 11, November 1938.

which modern scientific methods, and more specifically the application of physical techniques, are playing in the unending war against crime. The contrast between present-day methods embodying scientific principles and those of an earlier era can be summed up no more aptly than in the amusing but pointed exclamation, "Shades of Wyatt Earp! The old boy would turn over in his grave if he could hear that," which a western officer was heard to make upon having the advantages of spectrographic examination pointed out to him.

While the spectrograph has been a familiar instrument in physical and chemical laboratories throughout the world for many years, because of its fundamental importance in these sciences, consideration of its possible application in crime-detection problems is relatively recent. Cognizant of the invaluable assistance already gained from scientific methods, and in line with its policy of exploring new methods of attack, the Federal Bureau of Investigation some time ago installed such an instrument in its technical laboratory in an effort to ascertain the extent of its application to law-enforcement work. The rapidly increasing number of instances in which it has proved of value already indicates that there is a definite place for it in this field, in spite of the fact that only the surface has been scratched in exploring its possibilities.

Although the instance cited above indicates spectrographic results to be important from an affirmative evidentiary standpoint, it should be noted that its results may be equally valuable purely from an investigative standpoint as exemplified in the following case in which an extortionist identified the proposed pay-off spot by the simple process of painting a rock white at the desired location. During the subsequent investigation, special agents of the Federal Bureau of Investigation removed small flakes of this white paint and submitted them to the Bureau's technical laboratory together with specimens of white paint recovered from the home of a suspect. A spectrographic analysis of the paint used by the extortionist indicated it to be of a zinc base type whereas a similar analysis of the suspected paint showed it to possess a titanium base, and therefore to be not identical with the paint removed from the rock, a result which could have been obtained only with difficulty, if at all, by the usual chemical procedures because of the limited amount of material available for analysis.

Although the science of physics has contributed in some manner or other to almost every branch of crime detection, it is difficult, because of the overlapping nature of the various sciences today, to isolate and attribute specific improvements or techniques to physics alone or to any other single branch of scientific endeavor, such improvements or techniques in most instances having been rather the

result of a gradual development in several allied fields. However, by noting the relation and application of various portions of the electromagnetic radiant energy spectrum to specific crime detection problems it is believed that a fairly representative, even if necessarily somewhat brief and incomplete, picture of the subject as a whole may be presented.

Leaving the fascinating subject of spectrographic analysis which in its broadest sense may encompass a relatively large portion of the spectrum, and disregarding possible application of cosmic and radioactive gamma radiation which at the present are of little more than academic interest in relation to crime detection, there is found at the short wave length end of the spectrum a powerful ally to law-enforcement work in the X-ray. Probably the most important use to which this valuable aid is put in police work lies in its application to the examination of packages suspected of containing explosives. Each year finds its quota of persons horribly mutilated or of homes and business establishments wrecked by such bombs, and the problem confronting the officer who is charged with the responsibility of investigating and destroying these weapons of a crazed mind is a very real one. Fortunately, it is now possible in many instances through the agency of the X-ray to ascertain the contents of a suspected package without opening or otherwise disturbing the package in any way, thereby permitting appropriate action to be taken in the event the parcel is actually found to contain dangerous explosives.

Plate 1, figure 1, is an X-ray photograph taken of a model bomb showing the possibility of tracing the ignition wiring thus permitting the bomb to be opened harmlessly. Plate 1, figure 2, on the other hand, is an X-ray of a package received by a high Government official and suspected of containing explosives, but found as indicated to contain only a gavel presented by an admiring constituent, much to the relief of the recipient.

Above the X-rays in the radiant energy spectrum there is found a type of radiation known as ultraviolet light, so named, of course, because of its relation to the violet end of the visible spectrum which will be discussed later. This portion of the spectrum, in addition to exhibiting in general different selective reflection and transmission characteristics from those encountered in the visible region, further possesses the ability to excite to a state of luminescence many materials which are normally nonluminous, a phenomenon which is known as fluorescence.

Both of these properties find wide application in crime-detection problems. Inasmuch as the fluorescent radiation is in general different in wave length or color from the incipient radiation and in many instances is highly characteristic of the material illuminated,

it therefore offers one method of analysis to determine the nature of unknown materials received for examination. For instance, in connection with the investigation of rape cases, it frequently becomes necessary to examine clothing for the presence of seminal stains. Advantage is taken of the fact that such stains fluoresce brilliantly under the ultraviolet light, to localize certain areas which are then subjected to specific tests for the stain in question. The time saved by virtue of such a preliminary examination is immediately obvious.

Again, drawing on the field of document examination, we find the fluorescence of certain materials permitting their use as secret inks, invisible when viewed by ordinary lighting but standing out vividly in glowing contrast when subjected to ultraviolet illumination. Thus, the ultraviolet affords a rapid and convenient method of examination of documents or other evidence suspected of carrying a secret message. A special case of this application of ultraviolet is found in the examination of evidence containing obliterated writing, that is, writing which for some reason or other has been removed by physical or chemical processes. In many such cases there remain imbedded in the surface of the document, invisible to the eye, one or more constituents of the original writing ink which when viewed under the ultraviolet light reveal the fluorescent outline of the original. Plate 2, figure 1, is a photograph taken by the usual methods of a portion of a page from an account book belonging to the subject of a case under investigation by this Bureau. Evidence in the case indicated that the subject had represented the bank account to be much larger than it actually was. From a preliminary examination of the first entry shown in plate 2, figure 1, it was apparent that a number had been placed before the entry and then subsequently removed, although it was not possible to tell definitely what the number had been. When placed under the ultraviolet light, however, a "4" was seen to stand out in a faint fluorescent glow, before the original entry. This "4" is clearly visible in illustration plate 2, figure 2. The evidence made available through the use of ultraviolet light in this instance was of material assistance in the subsequent prosecution and conviction of the subject.

In order to utilize the selective reflection and transmission characteristics which several materials exhibit for the ultraviolet region, it is necessary to employ the action of the ultraviolet light directly on a photographic plate or other suitable recording medium. This process is readily carried out, of course, by the utilization of quartz optical systems and appropriate filters, resulting in incontrovertible evidence in those instances where the materials involved are such as to yield to this method of attack. Used to supplement each other, the two ultraviolet techniques outlined above have proved so valuable

that they have become an indispensable part of many routine examinations.

Immediately above the ultraviolet portion of the spectrum, there appear in orderly sequence the visible colors ranging from violet through extreme red, and inasmuch as these colors are directly involved in the all-important process of vision, it obviously would be futile to attempt, even in a much more comprehensive discussion than space permits here, to touch upon more than a very few of the applications to crime detection. Some of these, however, are so outstanding as to demand consideration.

Foremost among these is the microscope as we know it today. With these "seven-league glasses" it becomes possible for the expert to ascertain whether the wisp of hair found clinging to the door hinge of a suspected hit-and-run automobile is identical with comparison specimens of hair removed from the head of the child found lying unconscious with a fractured skull at the edge of the road near a small southern community; whether the printed fabric found wrapped around a murdered victim's neck in another instance is identical with similar fabric found at the home of a suspect; or whether the stain appearing upon an ax recovered at the home of a suspect is only rust, as claimed by the suspect, or is in fact a stain caused by blood of human origin received when the ax was utilized in a vicious attack on one of the suspect's neighbors.

By adding polarizing elements to the microscope, the petrographer is able to examine the colored interference patterns produced by birefringent crystalline materials and thereby determine, for example, whether the soil removed from the shoes of a suspect is similar in mineral content and structure to soil taken from the area where a safe, which had been stolen from a mercantile store, had been forced open and the contents looted.

In the field of firearms identification, we find a somewhat different modification of the microscope employed. Of several problems which properly fall within the scope of this work, the principal one deals with the examination of evidence—bullets and cartridge cases—in an effort to ascertain whether they have been fired from a suspected weapon recovered during the investigation. Such an examination is based upon the existence on both bullet and cartridge case of many minute markings, arising in the case of the bullet from its passage over the microscopic imperfections present in the gun barrel, and in the case of the shell from various imperfections in the breech face, firing pin, and similar sources. It has been amply demonstrated that each weapon creates a combination of such microscopic marks which is not duplicated by any other weapon; accordingly, each weapon, in effect, places its "fingerprint" upon all projectiles or shells

which are fired from it. The immediate problem thus resolves itself into a determination of whether the microscopic markings on the questioned bullet or shell coincide with similar markings upon test specimens fired by the examining expert from the suspected gun.

To meet this problem, which demands enlargement of the characteristic markings and provision for directly observing the coincidence or lack of coincidence between the sequence of the marks, the crime-detection laboratory has drawn upon the field of applied optics in creating an ingenious device known as the comparison microscope. This instrument not only furnishes the required magnification to make the minute markings distinctly visible, but in addition optically "splits" the specimens being compared in such a manner that images of opposite halves of the specimens are placed in proper juxtaposition to permit direct comparison of the marking sequence. In plate 3 is shown a photograph illustrating the manner in which the characteristic markings are seen to flow smoothly from one bullet into the other when both have been fired from the same weapon.

To illustrate the extreme value of this type of examination, attention is invited to a case in which a trapper in Alaska was found murdered in his cabin. Two suspects were located, each of whom was in the possession of a rifle of the type from which the fatal bullet had come. However, suspicion was directed more strongly toward one suspect than the other because of a prior criminal record which he was found to have and further because of the presence of bloodstains on his clothing. Upon receipt of the two suspected weapons in the technical laboratory of the Federal Bureau of Investigation, test specimens were fired from each and by means of the comparison microscope were compared with the fatal bullet. When this examination had been completed, it was found that the fatal bullet had been fired from the weapon belonging to the suspect toward whom the finger of suspicion had pointed less strongly, thereby completely exonerating the suspect with the prior criminal record. The bloodstains appearing upon the latter's clothing were found not to be of human origin, the suspect having previously claimed that they were caused by reindeer blood. Thus, it will be seen that the examination not only assisted very materially in the solution of the case, but even refuted circumstantial evidence tending to point to another suspect.

It is also of importance to note that the comparison microscope is not by any means limited in its application to the examination of firearms evidence. Whenever two objects of differing hardness are forcibly placed in contact, markings characteristic of the surface imperfections of one are invariably impressed upon the other. For example, a pair of bolt clippers used by a burglar to gain access to a business establishment may readily be identified as the instru-

ment actually used, by virtue of the microscopic marks which small dents and other imperfections in its cutting edges leave upon the severed ends of the window bars.

Case after case could be cited, each with a different story to tell, illustrative of the endless manner in which applied optics in the visible region of the spectrum has yielded a welcome solution to an otherwise difficult problem. However, space will not permit a more detailed discussion.

Corresponding to ultraviolet light lying beyond the short wave length at the end of the visible spectrum, there appears above the limit of visibility at the long wave length end, light which is known as infrared. This portion of the spectrum also has been found to possess certain characteristics which are of value to the scientific investigator; chief among these is the ability of infrared radiation to penetrate materials which are normally opaque to the unaided eye. As an example of this property, plate 4, figure 1, shows a photograph by ordinary process of an obliterated return address appearing upon an envelope in which an anonymous derogatory letter was mailed. It will be noted that the obliteration has been carried out by marking over the original form with ink. Aware of the characteristics of the infrared portion of the spectrum, the examiner immediately photographed the questioned area utilizing suitable optical filters and special photographic plates sensitized to this type of radiation. Plate 4, figure 2, shows the resulting photograph, clearly revealing the original printed return address through the overlayer of ink which now appears only as a light smudge. Here again by properly applying familiar principles of selective optical absorption, the source of the stationery employed by the anonymous writer was readily ascertained. Without the utilization of infrared photography much time and effort might have been required to accomplish the same end.

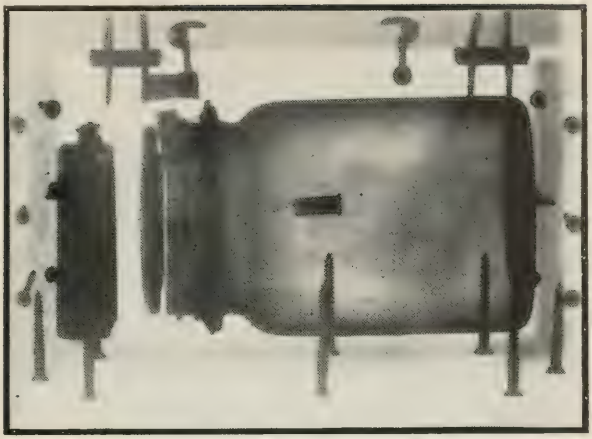
Another instance involves the examination of a leather money bag found on the person of a desperate criminal following his arrest. Other equipment in the possession of this criminal included 24 sticks of dynamite, a supply of nitroglycerin, numerous travelers checks, and a supply of weapons.

Visual examination of the money bag, as indicated in plate 5, figure 1, disclosed no identifying data which would be of assistance in tracing it. However, upon its receipt in the technical laboratory of the Bureau, infrared photographs clearly disclosed the name of the bank where it had originated, as shown in plate 5, figure 2.

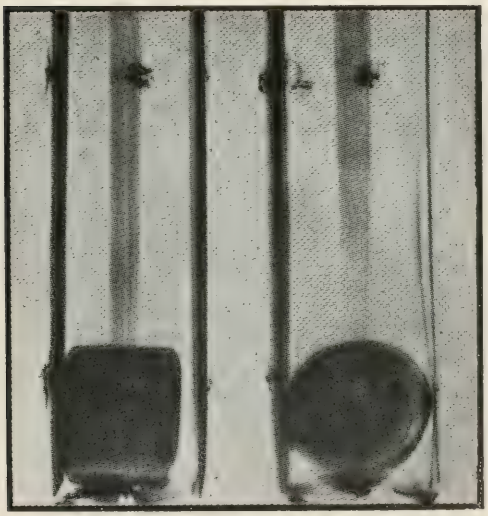
Moving to the long wave length portion of the radiant energy spectrum, the contribution of radio to law enforcement must be acknowledged. The rapidity with which radio as a means of com-

munication has been accepted by law-enforcement agencies throughout the country is ample proof of its value to such organizations. The ability to transmit to the farthest corners of the State, pertinent information relative to a crime almost before the perpetrator has completed the act, thereby rendering it extremely difficult, if not impossible, for him to escape, is a development of the utmost importance, particularly in view of the swift modes of transportation available to the criminal of today. In addition to furnishing an unparalleled means of communication the principles of radio have been utilized to throw protecting "fields" about homes or other specific areas, permitting actuation of almost any desired type of alarm upon the entry within the protected area by an intruder.

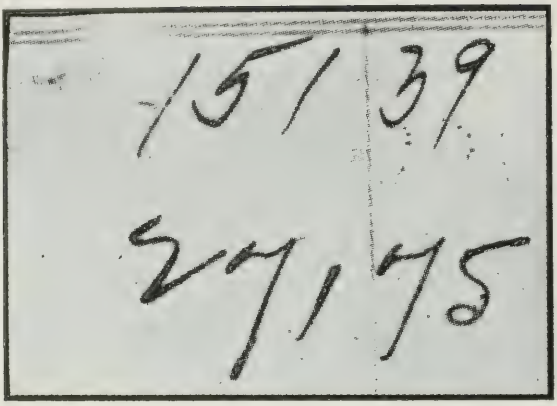
It is again to be emphasized that the few examples given above represent only a very small number of the myriad applications through which physical science has been of assistance to law enforcement. Indeed, reviewing the results which modern scientific methods have brought to crime detection, one is constantly tempted to ask with an earlier school of thought, "What more is there to be discovered?" only to be answered with a new development, startling in its implication and promise.



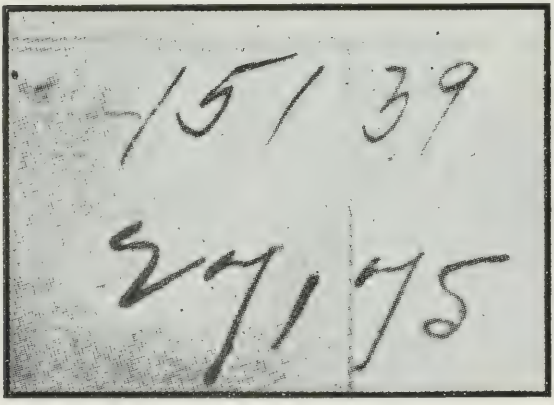
1. X-RAY PHOTOGRAPH OF A PACKAGE CONTAINING A MODEL BOMB.



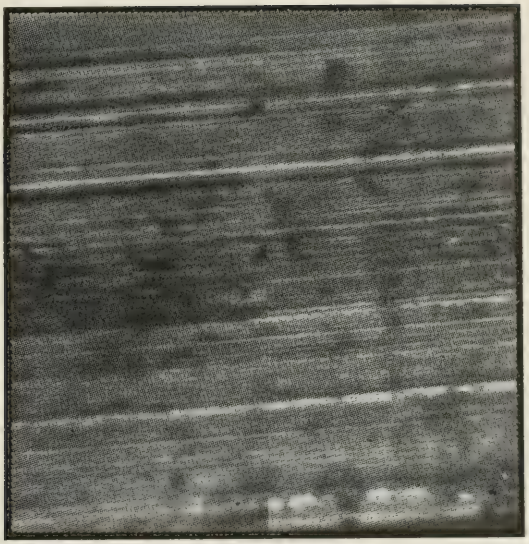
2. X-RAY PHOTOGRAPH OF A PACKAGE SUSPECTED OF CONTAINING EXPLOSIVES BUT SHOWN TO CONTAIN ONLY A GAVEL.



1. PHOTOGRAPH OF AN ACCOUNT BOOK, SHOWING THE REMOVAL OF A FIGURE BEFORE THE 15139.

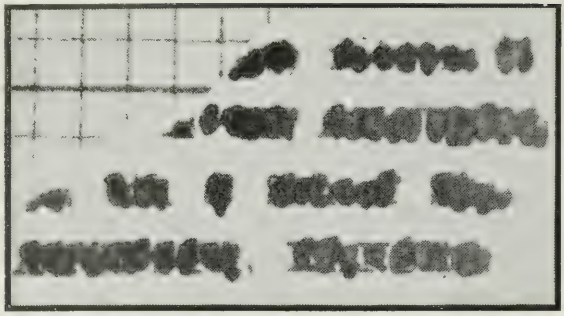


2. THE SAME PAGE OF AN ACCOUNT BOOK UNDER ULTRAVIOLET LIGHT; THE REMOVED FIGURE IS SEEN TO BE A 4.

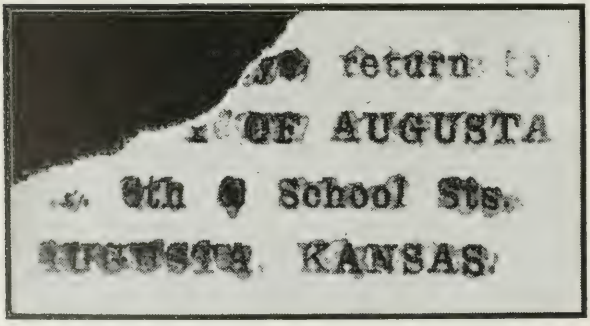


PHOTOGRAPH OF TWO BULLETS FIRED FROM THE SAME GUN AS SEEN UNDER THE COMPARISON MICROSCOPE.

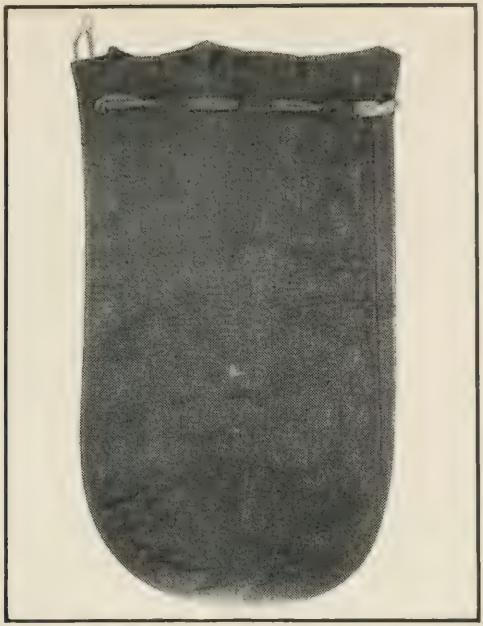
The characteristic markings flow smoothly from one bullet into the other.



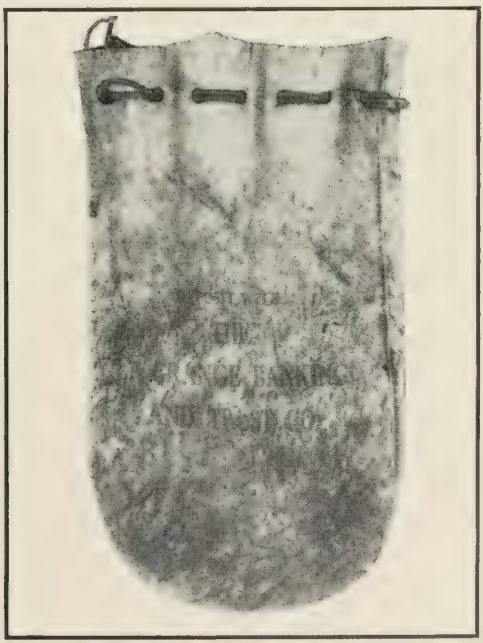
1. ORDINARY PHOTOGRAPH OF AN OBLITERATED RETURN ADDRESS.



2. PHOTOGRAPH OF SAME RETURN ADDRESS USING OPTICAL FILTERS AND PHOTOGRAPHIC PLATES SENSITIZED TO INFRARED RADIATION.



1. MONEY BAG FOUND ON A CRIMINAL UPON HIS ARREST, CONTAINING NO IDENTIFYING DATA.



2. SAME MONEY BAG PHOTOGRAPHED WITH INFRARED RADIATION, SHOWING LETTERING THAT PERMITTED THE DECIPHERING OF THE NAME OF THE BANK FROM WHICH IT CAME.

PHYSICAL INTERPRETATION OF THE WEATHER [1]

By Edgar W. Woolard
U. S. Weather Bureau, Washington, D. C.

[With 4 plates]

In the days of ancient Greece, the word "meteorology"—or, rather, its Greek equivalent, *μετεωρολογία*—was introduced to designate a subject that, even then, was already old, namely, knowledge and lore of the weather and other phenomena of the atmosphere. The word "meteor" was then used as a general term for any atmospheric phenomenon; this still is the preferred meaning given in modern dictionaries, but the more common usage now is for astronomical meteors, which in ancient times were, like comets, thought to be entirely of atmospheric origin and were included under meteorology along with a number of other phenomena not now considered to come within its field. During the centuries since Aristotle wrote the earliest known formal treatise on meteorology, the scope of the subject has gradually been narrowed, until the modern tendency is to restrict it to only the phenomena that are directly involved in the weather, excluding even other atmospheric phenomena and drawing more or less of a distinction between meteorology and climatology.

It is not difficult to show that meteorology, in the preceding meaning, is a branch of physics (principally "classical" physics), and it is significant that many of the most notable contributions to meteorology in the past have been made by physicists. The state of the weather at a given time and place is specified by the values of six quantities known as the meteorological elements, namely, air temperature, barometric pressure, wind velocity (direction and speed), humidity, clouds, and precipitation (rain, snow, hail, etc.). Now, these elements are completely determined by the temperature, pressure, density, and three velocity components of the air, and its total solid, liquid, and gaseous water content; clearly, therefore, the weather is essentially a dynamic and thermodynamic phenomenon.

Unfortunately, formidable difficulties are encountered in attempting to base the systematic development and the practical applications

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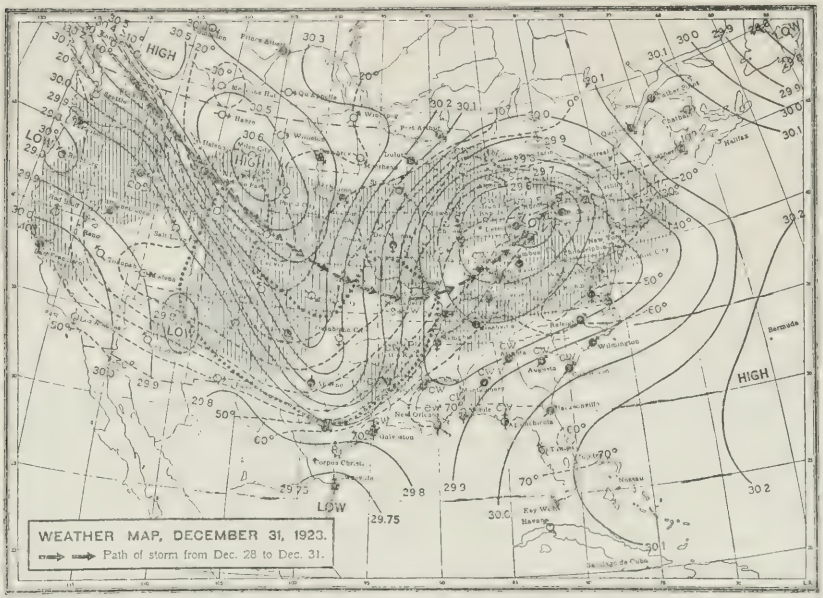


FIGURE 1.—Typical synoptic weather map, showing extratropical cyclone and anticyclone. The attendant wind circulations are shown by the arrows, which fly with the wind; isobars (solid lines) connect stations that have equal barometric pressures; isotherms (dotted lines) connect stations that have equal temperatures; shaded circles indicate clouded skies, *R*, rain, *S*, snow, and cross-hatched areas are regions over which precipitation has fallen during the preceding 24 hours. *CW* indicates cold wave warning; and the heavy dotted line encloses a region of marked temperature fall during the preceding 24 hours. (Compare with examples of analyzed maps, figure 3 and plate 3, figures 1 and 2.)

of meteorology explicitly on principles of physics; even an empirical understanding of the storms and irregular weather changes of temperate regions was slow to develop. The standard method of representing the weather conditions over a given region at any particular time is by means of the familiar synoptic map which is prepared from observations taken simultaneously at a network of stations distributed over the region, and which shows the geographic distribution of the meteorological elements (fig. 1). The synoptic map was introduced into meteorology early in the nineteenth century by Brandes and Redfield; and after the invention of the electric telegraph it came into daily use, for delineating and forecasting weather conditions, among the national meteorological services that were established in the principal countries of the world soon after daily telegraphic charts were first regularly issued in France in 1863. The daily synoptic map has been a powerful aid to meteorological investigation, while weather forecasting from these maps has rendered invaluable service ever since its inception; but even long after the development of theoretical meteorology on an exact physical basis had

been initiated (largely through the work of William Ferrel in the United States about 1855, pl. 2), progress was relatively slow in the attempt to interpret the current weather phenomena shown on the synoptic charts in terms of the physical processes in operation.

Weather forecasts were based fundamentally on the fact of observation (demonstrated by Benjamin Franklin, Leverrier, Fitzroy, and Buchan) that existing weather conditions travel over the globe in a fairly regular manner from day to day, altering more or less as they move (fig. 1 and pl. 3, figs. 1 and 2); and from a detailed study of the daily movements and transformations recorded on series of past synoptic charts, it is possible to estimate from a given current map the weather that will occur in the near future. For the most part, weather phenomena were empirically associated with the barometric pressure distribution, particularly with the cyclones or "lows" (regions of relatively low pressure), and anticyclones or "highs" (regions of relatively high pressure), which are continually moving over the temperate regions; and the emphasis was mainly on the weather conditions that had in the past been observed usually to accompany the particular movements and developments of these pressure formations that were to be expected on the basis of past experience, with little consideration of physical explanations and almost no attempt to make direct use of any physical principles.

The obstacles arise partly from the complexity of the phenomena, and partly from the difficulty of securing adequate observational data and effectively utilizing them. A complete investigation of the weather phenomena over a given region requires regular observations at fairly frequent intervals, both from the surface of the earth and aloft to moderately great heights in the free air, over a territory that extends far beyond the limits of the area under immediate consideration; a satisfactory understanding of the weather over the entire continental United States, therefore, would necessitate adequate data for at least the region from the mid-Pacific Ocean to Bermuda and from northern Alaska, Canada, and Greenland to Mexico and the West Indies, and it would be desirable to extend this area over a still larger part of the northern hemisphere. This ideal is far from having yet been attained, and much remains to be learned as to how to interpret and apply even all the data that now are available; but during recent years, notable increases have been effected in the number of reporting stations, including ships at sea and stations for upper air soundings, as well as in the extent of territory covered by the observing network, and in the completeness and frequency of the observations; and steady progress has been made in utilizing the data effectively, from both the empirical and the physical viewpoints.

The empirical association of weather conditions with pressure dis-

tribution, which prevailed from the earliest days of synoptic meteorology, was naturally suggested by the daily maps. It is, moreover, consistent with the fact of common experience that the "winds" are one of the principal immediate factors in daily weather; because it is the field of pressure which directly determines the flow of the air that constitutes the wind, while other weather phenomena are more or less directly produced by, or are incident to, the motions of the air. Great difficulty has been encountered in attempting to obtain from observations of the winds a satisfactory comprehensive knowledge of the atmospheric circulation over the globe, but for the purposes of the present discussion it is sufficient to recognize that the air motions which make up the circulation of the atmosphere as a whole constitute a complex and ever-varying system of innumerable different interacting currents by which great quantities of air are often transported from place to place over long distances; and during recent years, attention has been directed more and more to these air streams themselves—their motions, extent, and physical properties, and the relations of weather phenomena thereto—instead of being, as in the earlier days of synoptic meteorology, almost wholly concentrated on pressure formations as such.

It has been more or less vaguely realized for more than a century that on many occasions two atmospheric currents, markedly different in velocity and temperature, and sharply separated, may flow adjacent to each other and produce distinctive weather phenomena as one succeeds the other at a given place; this idea was clearly expressed as early as 1828 by H. W. Dove, who ascribed the storms of temperate latitudes to conflicts between polar currents and equatorial currents. Only very limited observation is needed to reveal striking instances in which all of the meteorological elements change simultaneously and abruptly in a pronounced manner (fig. 2), as the boundary between two different currents sweeps over the observing station, the transition from one to the other amounting practically to an actual discontinuity. Such moving discontinuities, often hundreds of miles in length, between adjacent currents, frequently are quite conspicuous on synoptic charts (fig. 3); they have long been recognized by the forecaster, and were the subject of extensive theoretical investigations by Helmholtz and Margules. It was not until during the World War, however, that an intensive effort was made to investigate the separate currents in detail, explicitly as a basis for the interpretation of the phenomena shown on the daily maps. The investigation was initiated in Norway, after the Scandinavian countries had ceased to receive meteorological data from other countries because of the war. On very detailed surface charts, prepared from unusually comprehensive observations at an exceedingly dense network of stations, it

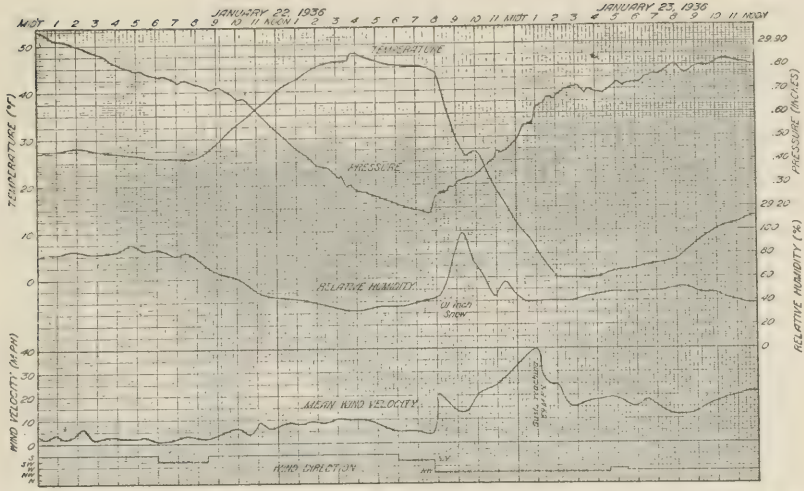


FIGURE 2.—Variations of the meteorological elements at Washington, D. C., January 22–23, 1936, recorded by self-registering instruments. Note the simultaneous abrupt changes in all the elements at about 8 p. m., January 22, 75 meridian time, as the boundary between a weak southerly current and a strong northwesterly current passed over the city; the total drop in temperature was nearly 50° F. Considerable property damage from wind occurred. See also figures 3 and 4.

was found that a number of individual currents ordinarily could be identified and followed from day to day; they differed more or less from one another in direction of movement, speed, temperature, and other characteristics; and often ended abruptly against one another, with the clouds, precipitation, and other weather phenomena definitely related to these discontinuities.

It may be shown from dynamical theory that two atmospheric currents with different temperatures and velocities may, on the rotating earth, flow side by side in mutual dynamical equilibrium, provided the surface of discontinuity between them is inclined at an appropriate (in general, small) angle to the horizontal, with the colder current lying in wedge form under the warmer (fig. 4). If the conditions necessary for this dynamical equilibrium are not fulfilled, however, a disturbance develops at the boundary between the two currents, and may result in the formation of a traveling cyclone. The warm current advances against, and flows up over, the cold current, while in the rear of the disturbance the cold air sweeps in under the warm current (figs. 5, 6). In the regions where warm air is forced to ascend, the adiabatic cooling may lead to condensation and precipitation of the admixed water vapor. This general conception of the cyclone is the outgrowth of ideas successively expressed and elaborated during the past hundred years by Dove, Helmholtz, Blasius, Margules, Shaw, J. Bjerknes (1919), Solberg, (Bjerknes and

Solberg, 1922) and others; in an idealized schematic form, it is represented in figures 5 and 6, although of course actual cyclones usually depart more or less from the ideal. Much yet remains to be learned, however, about the detailed structure and the dynamical mechanism of the cyclone, concerning which several different theories exist.

Thus, it is not the cyclones and anticyclones as such that are important in determining the weather, but rather the interactions between the various moving air masses that are involved in the systems

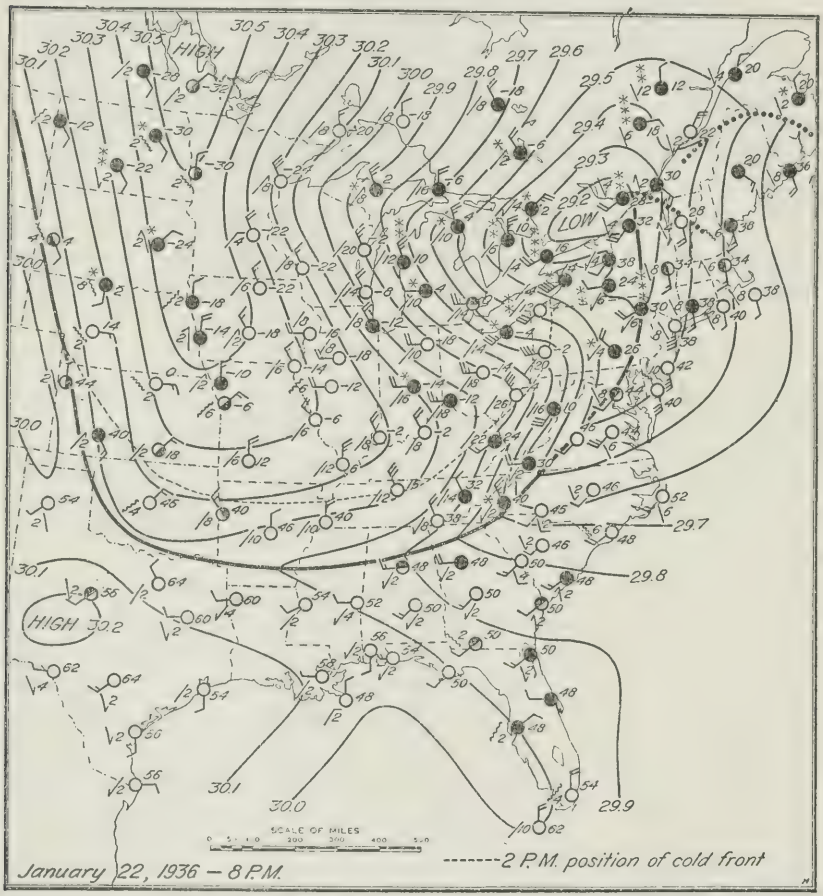


FIGURE 3.—Synoptic map of eastern United States at 8 p. m., 75 meridian time, January 22, 1936. The heavy solid line shows the boundary or "front" of advancing cold air, just before it reached Washington and produced the effects shown in figure 2. Arrows fly with the wind, and the number of barbs indicates the wind strength; the number to the right of each station is the Fahrenheit temperature; the number to the left or below is the net change in the barometer (in hundredths of an inch) during the preceding 3 hours, and the accompanying symbol shows the character of the barograph trace during that interval. Note the comparative uniformity in temperature over large areas ahead of the front, and the abrupt decrease at and behind the front; note also the abrupt change in the barometric tendencies at the front. See also figure 4.

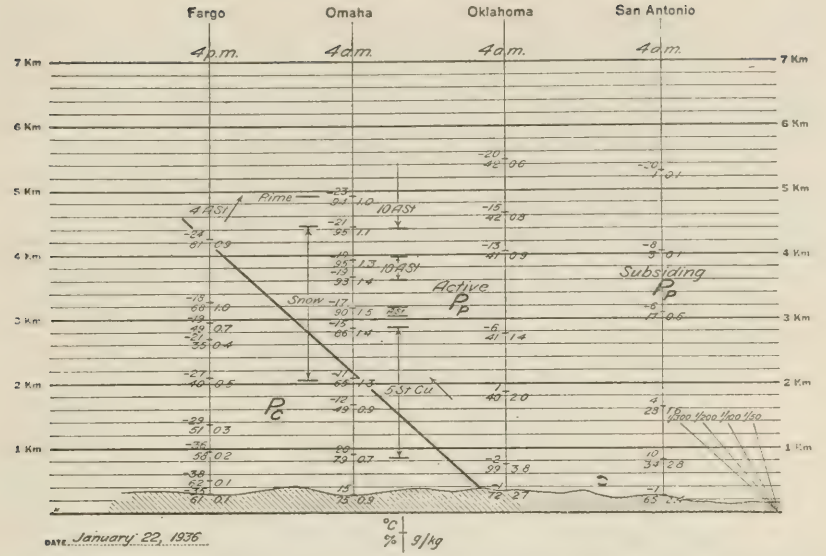


FIGURE 4.—Vertical (north-south) cross section through the cold front shown in figure 3, constructed from data obtained by airplane soundings in the early morning of January 22, 1936. The numbers show centigrade temperature, relative humidity, and moisture content in grams of water vapor per kilogram of air, at the points indicated, arranged as shown at the bottom of the diagram. Note how the cold (Pc) air lies in wedge form under the warmer air; the vertical scale is greatly exaggerated (see scale of slopes in lower right corner).

of winds that attend barometric pressure formations. The elaboration of a systematic technique for the delimitation of the individual currents on the daily maps, and the study of the weather phenomena produced by their interactions, have led to "air mass analysis," to which so much prominence has been given in recent years. Over large areas of the earth, especially in polar and in tropical regions, the meteorological conditions are so nearly uniform and steady, and the circulation so relatively weak or restricted for long periods that the atmosphere up to great heights above these areas takes on distinctive properties of temperature, moisture, and stability that are characteristic of the regions. For example, when air either stagnates, or else circulates for a long period, over the regions of the Gulf of Mexico and Caribbean Sea, it becomes warm, moisture-laden and unstable. Frequently an atmospheric current originates in one of these areas and transports large quantities of air to distant parts of the earth, as, for example, when a great body of intensely cold air pours out from the Arctic and flows down over the globe to lower latitudes, sometimes covering the larger part of the North American continent with its frigid winds (figs. 1, 3). Moving masses of air from different localities tend as they travel to retain many of the initial physical properties characteristic of their respective source

regions, especially at upper levels, although of course they gradually become more and more modified as time goes on by the conditions encountered during their progress. When air masses from widely separated places of origin, and with distinctly different properties, are brought into juxtaposition by the currents that are continually traversing the atmosphere, these bodies of air do not freely mix, but tend to retain their identity and to remain separated from one another throughout much of their history by more or less well-defined surfaces of discontinuity or sharp transition zones in temperature, humidity, and velocity; until eventually, after profound modification by the long continued action of external influences, they are

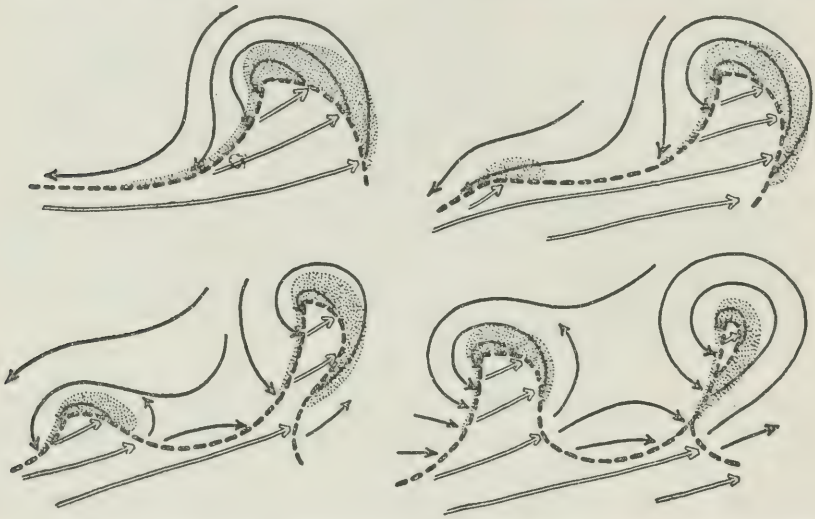


FIGURE 5.—Formation of an extratropical cyclone from a disturbance on the boundary between a cold and a warm current. See figure 6.

subject to mixture, dissipation, and ultimate disappearance as separate bodies. It is at the interfaces where different air masses meet, or so-called "frontal surfaces," that the processes involved in weather phenomena are in general most active, although many important phenomena also frequently take place within the body of an air mass. In the analysis of synoptic maps, it is necessary to identify and delimit the separate air masses, assign them to their places in some recognized classification of air masses according to source region and characteristics, trace their movements and progressive modifications from day to day, and determine the associated physical processes and their relations to the attendant weather phenomena.

With respect to their physical characteristics, air masses may be classified (Willett, 1933, 1936) first into tropical and polar, and each of these types further subdivided into continental and maritime,

according as the source region was over land or ocean; still further subdivision may be made on the basis of the geographical location of the source region. For example, in the United States, two types of tropical maritime air are important—tropical Pacific (TP) and tropical Atlantic (TA) . When an air mass becomes significantly modified from its original state, it is designated as a transitional mass and is distinguished by prefixing a capital N to its symbol—as, for example, NTA. A wholly satisfactory classification is difficult

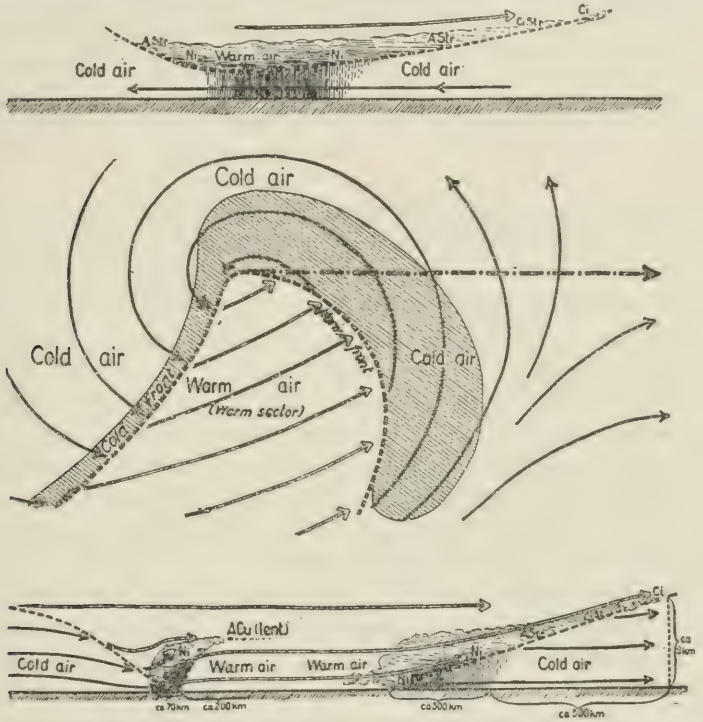


FIGURE 6.—Idealized extratropical cyclone formed by the process illustrated in figure 5. with vertical (east-west) cross sections through the northern part (above) and the southern part (below).

to achieve; and at the present time the tendency is to classify air masses on the basis of whether they are warmer or colder than the surface over which they are flowing, rather than on the geographical basis used in the diagrams accompanying this paper.

The development of air-mass analysis has greatly stimulated efforts to obtain more adequate data and to devise effective means for their application to the physical analysis of day-to-day weather and the interpretation of synoptic maps. The daily location of the "fronts," or lines on the surface of the earth which bound the different air masses, presents a difficult problem in practice. The contrasts

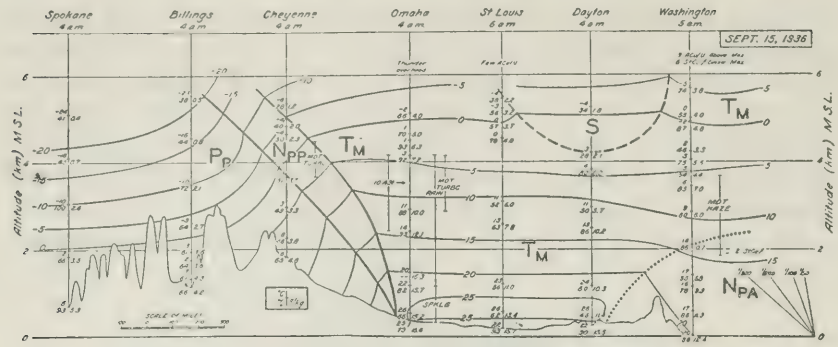


FIGURE 7.—East-west vertical cross section through the atmosphere, showing conditions aloft shortly before the time of the map in plate 3, figure 1 (cf. explanations in legend to figure 4).

frequently are obscure and may not exist in all of the physical properties; broad and diffuse transition zones sometimes take the place of true fronts. Success in the analysis requires that appropriate and adequate data be available to a trained and experienced personnel. In particular, a network of aerological soundings to fairly great heights is indispensable, and until upper-air data could be made quickly available by the introduction of airplane soundings, air-mass analysis could not receive extensive application in daily work. The current characteristics of an air mass depend on both its source and the modifications it has undergone during its progress away from the source region; these modifications, which usually tend to weaken the distinctions, are in general much more rapid and extensive near the surface of the earth than aloft. Furthermore, surface observations alone frequently do not reveal conditions and physical processes aloft which on many occasions are the principal cause of important phenomena at the surface, and without a knowledge of which the latter cannot be explained or foreseen, nor the surface map interpreted. Methods are now being rapidly perfected for obtaining aerological observations under all conditions of weather, and from a denser network, by means of the radiometeorograph or "radiosonde"—a mechanism which is carried aloft by a small balloon, and by which pressure, temperature, and humidity are caused to actuate a short-wave radio transmitting apparatus that conveys a record to radio receiving apparatus on the ground. Vertical cross sections through the atmosphere (figs. 4, 7), so far as they can be constructed from data now available, are being used to supplement the surface map and the mere pilots of upper-air data against height (Willett, 1935, 1935a).

Examples of analyzed maps are shown in plate 3, figures 1 and 2. When the movements of the currents are such that colder air is ad-

vancing over regions occupied by warmer air, the front between the two air masses is called a cold front; if warmer air is advancing into regions occupied by colder air, the discontinuity is called a warm front. Advancing warm air always tends to overrun colder heavier air; while advancing cold air tends to underrun warm air. The discontinuity formed when a cold front overtakes a warm front and displaces the warm air formerly between them to a higher level is known as an occluded front. Cold fronts often give rise to the well-known squall lines or wind-shift lines. Along the separating frontal surfaces, the overrunning of warm air over the slopes of cold air masses, or the lifting of warm air by underrunning cold air, leads to adiabatic cooling and eventually cloud and perhaps precipitation. The interaction of a cold and a warm air mass often leads to the development of a cyclone, with its center on the front. In the search for the fronts, important evidence is provided by temperatures, winds, dewpoints, pressure tendencies (that is, the pressure changes during the 3 hours preceding the observations), cloud forms and sequences, precipitation, and other auxiliary information (Byers, 1937).

A number of special procedures have been devised for putting the data, especially those from the upper air, into a form that will facilitate their effective and convenient application in practice, both for the identification of air masses from place to place and time to time, and also for the purpose of analyzing the physical conditions and processes; investigations for this purpose have in recent years led to a particularly noteworthy development of the thermodynamics of atmospheric phenomena, and of practical means for applying it. Meteorological thermodynamics involves the investigation of the energy transformations and sequence of thermodynamic properties and states, during specified processes, in the atmosphere (Brunt, 1939; Humphreys, 1929). When, for example, humid air is forced to ascend in the atmosphere, it comes under less and less pressure and expands and cools adiabatically; if this process continues, condensation and precipitation eventually take place. The resulting mixture of dry air and widely variable amounts of water distributed in continuously changing proportions between the gaseous, liquid, and solid phases, in the gravitational field of the earth, forms a highly complicated system; and the derivation of mathematical equations of state to show the condition of the system and the sequence of phenomena throughout the process is an intricate problem which involves relations far more complex than the familiar $PV=RT$ of elementary physics.

For purposes of air mass identification, conservative properties of the air are of especial importance. Some properties are more conservative than others during the modifications to which air masses are usually subject; in seeking an index which will remain as nearly as

possible constant, two quantities known respectively as specific humidity and equivalent potential temperature have been found especially useful: The specific humidity is the mass of water vapor per unit mass of humid air; the equivalent potential temperature is the temperature to which air would come if subjected to a pseudoadiabatic lifting (that is, a lifting which is adiabatic except that all condensation products drop out immediately upon formation) until all moisture was precipitated, followed by an adiabatic return to a standard pressure.

In developing methods for representing the data from upper air soundings in a form that will show the meteorological import of the physical conditions and be adapted to practical needs, a number of special thermodynamic diagrams have been devised and have come into regular use (Refsdal, 1935; Rossby, 1932; Woolard, et al., 1926). In general, these diagrams consist of networks of lines, referred to appropriate coordinate systems, which show the thermodynamic states of atmospheric air over a wide range of conditions and by which the changes of state and the energy transformations during any prescribed process may be traced out; they correspond to the "indicator diagrams" of physics and engineering, but are much more complex. By plotting the data from a sounding on one of these diagrams, the conditions in the vertical with respect to stability, available energy, etc., at different levels in the atmosphere may be determined; and many of the phenomena to be anticipated under the existing meteorological circumstances may be inferred. On the so-called tephigram, for example (fig. 8), the sounding is plotted on a chart with absolute temperature as abscissa and entropy as ordinate, and with a background of lines that show pressures, water vapor contents, and irreversible adiabats of saturated air; on the "Rossby diagram," which is particularly useful for bringing out significant properties of the air, the sounding is plotted with the so-called mixing ratio (mass of water vapor per unit mass of dry air) as abscissa and potential temperature of the dry-air component of the atmosphere as ordinate, and with a background of lines that show equivalent potential temperatures, and pressure and temperature at the condensation level. Other widely used charts include the adiabatic chart, the emagram, and the Refsdal aerogram.

One of the methods most recently applied in daily practice as an aid in the representation and physical analysis of phenomena is the construction of charts that show the meteorological conditions on selected isentropic surfaces (surfaces of constant potential temperature) in the upper air, instead of on horizontal surfaces. These isentropic charts were suggested by Sir Napier Shaw some years ago, but their practical construction and use requires, of course, a network of daily

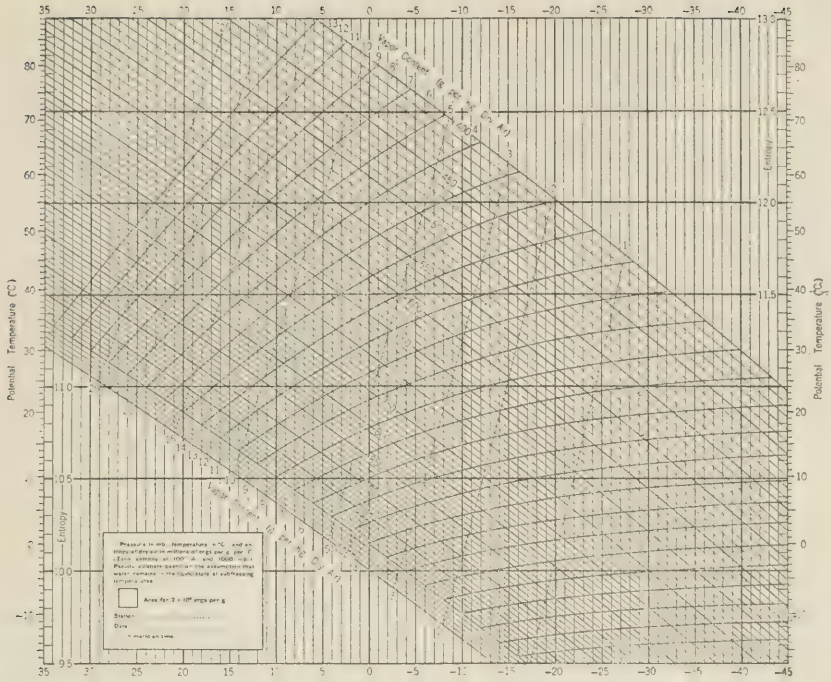


FIGURE 8.—Thermodynamic diagram for plotting the so-called tephigram of an upper air sounding. The observed temperature (centigrade) is plotted as abscissa, against entropy as ordinate (an equivalent logarithmic scale of potential temperature is added for convenience). The curved lines show the sequences of thermodynamic states followed by saturated air in pseudoadiabatic processes under different initial conditions, as specified by realized entropy of the air, temperature, pressure in millibars (shown by sloping solid straight lines) and saturation water vapor content (sloping dashed straight lines). An area on this diagram represents energy. The relations of the graph of the sounding to the isentropic lines and pseudoadiabats indicate conditions of stability in the atmosphere, and the amount of energy available or required for the occurrence of meteorological processes.

aerological soundings. The charts show (among other things) the elevation contours of the selected isentropic surface as indicated by the barometric pressure distribution over the surface; the distribution of specific humidity as indicated by the values of the pressure at which condensation would begin in an adiabatic expansion; and the wind velocity over this surface (fig. 9). The motion of the upper air is in general so nearly adiabatic, as long as no condensation occurs, that the flow must everywhere be practically along an isentropic surface. The flow of individual dry and humid currents in each surface, and the gradual lateral mixing of these currents over the surface, can be followed from day to day by means of the specific humidity. The extent to which the motions of the currents are upward or downward along the slopes of the isentropic surface, together with the conditions of relative humidity, condensation levels, and motion of

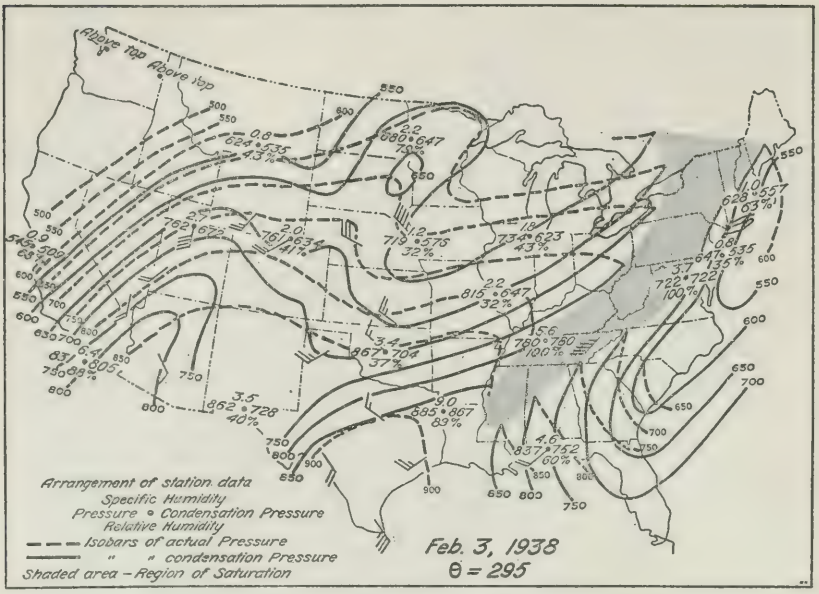


FIGURE 9.—An isentropic chart: A synoptic map of the surface in the upper air over which the potential temperature at the time was everywhere 295°. The places at which the condensation pressure becomes equal to the current pressure outline a cloud-covered region in most of which precipitation occurred at the surface of the earth.

the surface itself, is intimately related to the occurrence of cloudiness and precipitation, and other meteorological processes. Isentropic charts have shown considerable promise both for purposes of hydrodynamical investigations of atmospheric motions and for practical forecasting.

It must be emphasized that the physical analysis of maps and cross sections is quite distinct from the making of a forecast; the analysis must be followed by a determination of the expected displacements, transformations, and developments of the fronts, air masses and pressure formations, and an estimate of the weather conditions that will accompany them. Important progress has been made in developing methods for this purpose also on a quantitative physical basis; but the unusual demands of practical meteorological work, particularly the exceedingly limited time within which forecasts must be completed and issued, together with the extraordinary complexity of the phenomena involved, the great volume of data necessary and the wide areas from which they must be gathered, make it peculiarly difficult to adapt the results of theoretical investigations to meet the needs of applied meteorology. The majority of attempts to achieve anything that approaches an exact mathematical calculation of future weather on the basis of dynamical and physical

theory have not been successful in practice, although some of them are of great theoretical importance (Woolard, 1936). Among the investigations with the greatest immediate practical promise, the most noteworthy, perhaps, are those by Sverre Petterssen of the Norwegian Meteorological Service, following earlier similar work by Gião and Angervo. On the basis of the ordinary kinematical theory of fluid motion, he has developed rigorous methods for a kinematical analysis of the synoptic chart in conjunction with the frontal and the thermodynamic analyses, and has derived procedures for detecting indications of important developments, and for calculating the movements and transformations of pressure systems and of fronts. His formulae (Petterssen, 1933, 1936), when used with judgment by an experienced forecaster, are a valuable aid (Weightman 1936, 1936a), although they do not contribute to the dynamical interpretation of the kinematic phenomena. Plate 3, figure 1 shows some results of applying Petterssen's methods which may be compared with the actual occurrences shown in plate 3, figure 2.

Under the influence of these and other modern developments, weather forecasting, at first exclusively empirical, is now progressing along sound physical lines; and it has become practicable during recent years to supplement, though not replace, the empirical methods of weather forecasting, as developed in the nineteenth century on the basis of experience alone, with practices based on an understanding and an explicit application of the physical laws to which the phenomena conform (Weightman 1936, 1936a). For a long time to come, however, weather forecasting must continue to be a combination of physical reasoning with methods based on accumulated practical experience with synoptic charts. We cannot yet, and perhaps may never, safely do without the empirical judgment of the experienced forecaster.

Meanwhile, it may reasonably be expected that all investigations designed to elucidate the physical mechanism of weather phenomena will not only contribute toward a better understanding of these phenomena, but also lead, because of this increased understanding, to an eventual increase in the precision, and an improvement in the accuracy, of forecasts; and will moreover have the distinct advantage of making weather forecasting less of an esoteric art, irrespective of the extent to which they may effect actual improvements over the results already obtainable by empirical practices. The problems presented by weather phenomena and their prediction offer a fertile field of research for the application of the classical physics. In addition, the weather provides many examples of physical phenomena, on an impressive scale and often of a spectacular character (pls. 1, 4), which afford excellent illustrations of important physical principles;

some of these illustrations are of peculiar interest and educational value, because the operation of familiar physical principles in the atmosphere frequently leads to results quite at variance with what is to be expected on the basis of ordinary experience, since, on the scale of atmospheric phenomena, many influences that are negligible in the laboratory become the dominating factors (Humphreys, 1934). Weather phenomena are constantly in evidence, and vitally affect the daily life of everyone; the immeasurable pleasure to be derived from an ability to understand and appreciate this familiar element of our physical environment is ample reason for devoting attention to it in the general teaching of physics.

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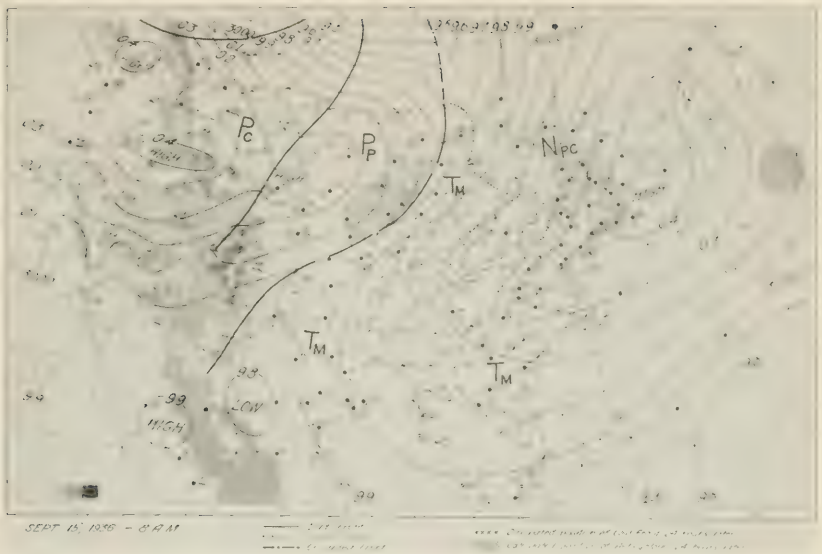
1. TORNADO CLOUD, OKLAHOMA CITY, MAY 12, 1896.



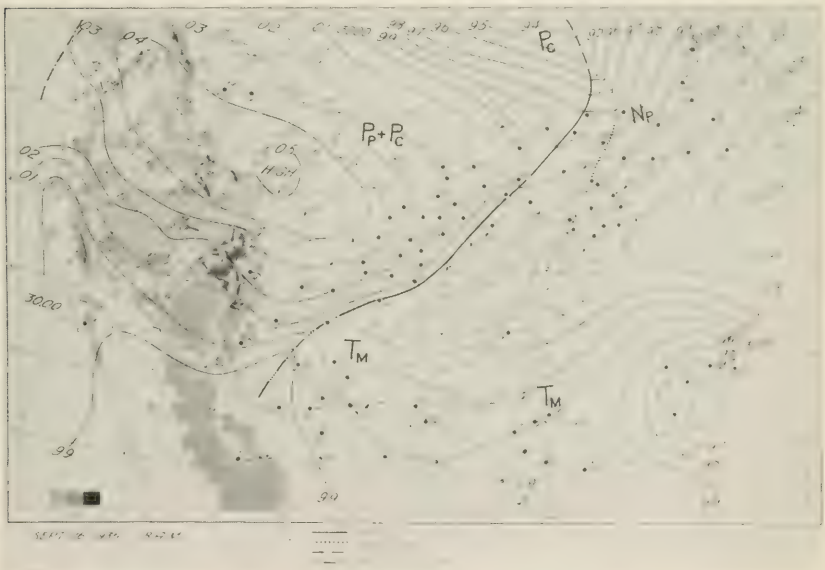
2. LIGHTNING FLASH IN A THUNDERSTORM CLOUD.



WILLIAM FERREL, 1817-91; AMERICAN PIONEER INVESTIGATOR OF THE DYNAMICS OF ATMOSPHERIC PHENOMENA.



1. ANALYZED SYNOPTIC MAP, SEPTEMBER 15, 1936, 8 A. M., 75TH MERIDIAN TIME.
(See also fig. 2, below, and fig. 7.)



2. ANALYZED SYNOPTIC MAP, 24 HOURS LATER THAN FIG. 1 (ABOVE).
(See also fig. 7.)



THUNDERSTORM NEAR PENSACOLA, FLA.

HURRICANES INTO NEW ENGLAND

METEOROLOGY OF THE STORM OF SEPTEMBER 21, 1938[1]

By CHARLES F. BROOKS

Blue Hill Meteorological Observatory, Harvard University

The hurricane of September 1938 was a whirling, circular storm with very destructive winds spread over a diameter of 200 miles. At its center was the usual calm eye, some 40 miles in breadth. This vortex rushed northward to Long Island and New England with the speed of an express train, augmenting wind velocities to extremes of about 120 miles an hour on the east of the path of the center. The wind drove the sea water with such force that, when added to the rise in sea level due to the low pressure and thrown against the coast, the sea rose 10 to 17 feet above the expected level, in itself high water, the time being high tide.[1a] Towering surges on this combined astronomical tide and storm wave threw the sea to such heights that demolition was general along the exposed coast, and they came so suddenly that hundreds of persons, some of them at the shore to watch the fine surf, were engulfed and drowned. Flying spray incrusted windows; salt killed vegetation 20 miles inland, and traces were found even 50 miles from the raging sea. Inland, the rivers, already flooded by 4 days of tropical rains, added to the destruction.

The gale, roaring in great gusts over the countryside, broke off or uprooted some 275 million trees, damaged or destroyed thousands of buildings, and directly or indirectly downed nearly 20,000 miles of electric-power and telephone lines, darkening the homes of seven-eighths of those served by power lines and cutting off nearly one-third of the telephones. Many people were killed or injured by falling trees and chimneys, or flying debris. Twenty-six thousand autos were smashed. The damage was most extensive on the tops and flanks of hills, in and beyond gaps through which the wind was funneled, on leeward shores and the corresponding margins of meadows, golf courses, and other open stretches—even broad highways and railroad right-of-ways where they were approximately

[1] Reprinted with changes from The Geographical Review, vol. 29, January 1939.

[1a] For general summary see Neuman, F., Storm wave data for the New England hurricane of September 21, 1938. Bull. Amer. Meteorol. Soc., vol. 20, pp. 357–358, October 1939.

parallel to the wind. There were also lanes of destruction where a succession of vicious gusts had plowed into the woods, breaking off the first trees or uprooting them from the sodden ground, thereby opening the then unprotected trees to leeward to the destructive attacks of the subsequent blasts. Some 2.6 billion board feet of timber were thrown down, leaf pulp turned white houses green, and leaves that were not blown to pieces were "scorched" by the beating, desiccating, salty gale.

There were some 600 lives lost. The American Red Cross places the deaths at 488, with 100 additional missing and 1,754 injured. The W. P. A. survey[2] places the loss of human life at 682. The Red Cross also finds that 93,122 families suffered more or less serious property losses; that 6,933 summer dwellings, 1,991 other dwellings, and 2,605 boats were destroyed; also 2,369 barns and 7,438 other buildings; and 75,000 were damaged. One thousand six hundred and seventy-five head of livestock and one-half to three-quarters of a million chickens were killed. Railroad service between New York and Boston was interrupted for 7 to 14 days while 10,000 men filled 1,000 wash-outs, replaced nearly 100 bridges, and removed thousands of obstructions from the tracks, including a number of cottages and 30 boats—1 a fairly large steamer, which remained for 17 days on the track. The air lines carried 1,000 passengers a day. The total property damage is reliably estimated to have been at least $400,000,000.[3] Although the loss of life has been greater in a few other hurricanes, the damage to property in this storm was the greatest that ever occurred in a single storm anywhere in the world.

Such things had happened before—in 1815 and 1635—and had been vividly recorded in newspapers, meteorological records, and town chronicles,[4] and in Sidney Perley's Historic Storms of New England.[5] In fact, Perley describes 10 storms of hurricane intensity in 2½ centuries, and Tannehill lists 8 more, and there have been 4 more in the last 50 years,[6] which makes 5 or 10 New England hurricanes to a century and 1 that is especially fierce and widespread in each century and a half.

[2] New England hurricane, a factual, pictorial record. Federal Writers' Project, W. P. A., Boston, 1938. This is the largest of a great number of booklets, usually on a particular town, or area, or industry. A partial, briefly annotated list of these, and articles on the hurricane, compiled by Charles Rufus Harte, of New Haven, runs to more than 120 titles. Perhaps the best general illustrated magazine article is by F. B. Colton, The geography of a hurricane . . . Nat. Geogr. Mag., vol. 75, pp. 529–552, 21 figs., April 1939.

[3] Figures from Pierce, Charles H., The meteorological history of the New England hurricane of September 21, 1938. Monthly Weather Rev., vol. 67, pp. 237–285, 48 figs., August 1939. This is a very comprehensive discussion, including daily pressure and wind maps for the 6,000-foot and 10,000-foot levels and isentropic charts, and twice daily to hourly sea-level synoptic charts with air-mass fronts and station details of the weather.

[4] Quoted by Walter Channing in New England hurricanes, 1635, 1815, 1938. 16 pp. Boston, 1939.

[5] Salem, Mass., 1891.

[6] Tannehill, I. R., list of West Indian hurricanes, in Hurricanes: Their nature and history. Princeton, 1938.

ORIGIN OF THE STORM

The hurricane that devastated Long Island and New England on September 21, 1938, had its origin far east of Puerto Rico. On the morning of the 16th it was already of full hurricane strength; in fact, as early as the 13th a cyclonic circulation was in evidence in 37° W., 19° N.[7] This whirl was almost certainly that which formed on the night of the 7th over French West Africa, lat. 10°–20° N., long. 10°–20° W., between the northeast trade, the southwest monsoon, and the equatorial easterlies. The disturbance initiating the whirl formed in the interior, however, and moved westward to the coast. It was first noted as a weak low at Bilma oasis, in the south-central Sahara, on September 4.[8]

The direction (W. by N.) and speed (15 to 20 miles an hour) of progression of the hurricane as a whole were practically the same as the gradient wind in the general pressure field at the southern and western margins of the North Atlantic high. This high, centered south of Newfoundland, was attended by a broad stream of tropical air, which curved northward east of Florida. The hurricane moved along in this stream more or less as would have a floating balloon. Its entry into the stream may be considered as essentially accidental. But once in the stream, the effect of the hurricane was marked. The storm became a great whirl that sucked air into itself from a belt about 300 miles wide and discharged it upward, thereby putting it through the cyclonic "wringer." Within the Tropics this process did not alter the warm, moist character of the tropical air stream—the supply of moist tropical air was ample for long distances on each side.

Once the storm left the Tropics, however, it no longer had an unlimited supply of tropical air on its left. Polar air reached the southeastern States as the hurricane recurved. In fact, the arrival of this air probably helped the recurving; for its lower temperature increased the density of the atmosphere and thereby favored a slope in the upper-air pressure surfaces from east to west, a direction of slope that calls for a northward movement of the upper air.

The drawing of cool, dense air into the storm from the northwest and west favored a more and more rapid rise in pressure south of it as the incoming air got cooler and cooler with higher and higher latitudes—pressure at Hartford, for example, fell 0.4 inch one hour and rose 0.75 inch the next. This raising of the pressure on the south should have accelerated the northward movement of the center of

[7] Tannehill, I. R., Hurricane of September 16 to 22. Monthly Weather Rev., vol. 66 pp. 286–288, 2 maps, September 1938.

[8] Hubert, H., Sur l'origine africaine d'un cyclone tropical dévastateur dans la région de New York. Comp. Rend. Acad. Sci., Paris, vol. 208, pp. 456–457, 1939; Origine Africaine d'un cyclone tropical Atlantique. Ann. Phys. Globe France d'Outre-Mer, vol. 6, pp. 97–115, 17 figs., Paris, 1939. Reviewed in Geogr. Rev., New York, 1940.

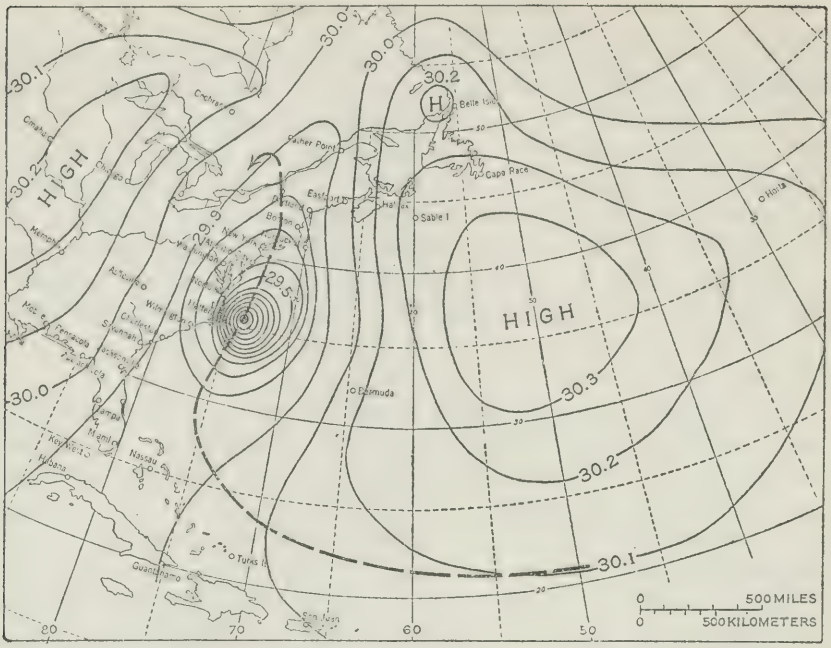


FIGURE 1.—Pressure map for September 21, 1938, at 7:10 a. m., and track of hurricane. (After Tannehill.) Pierce (op. cit., fig. 12) places the center farther east, on the 73d meridian, along which it moved straight northward till 7 p. m., when it was in west-central Vermont.

lowest pressure, even making it go faster than the general current. Moreover, the cool, dry air could not furnish more than half as much latent heat, the lifeblood of a tropical storm, as the warm, moist air had been providing. On the other hand, the 20° F. contrast in temperature between the east and west sides of the storm created potential energy that made up in part for the loss of latent heat, so that the rate of decrease in intensity was not rapid.[8a] Also, the storm moved northward so fast that the reduced energy had little time to make itself felt.

The gradual weakening of the storm over New England could have been accounted for altogether by the increased friction of the wind with trees, buildings, and hills of an average roughness of 9 m. (about 30 ft.) height, according to computations by Raymond Wexler.[9]

The circular pressure field of the cyclone merged, naturally, into the general pressure trough extending northward through New England. The pressure gradient on both sides steepened rapidly, particularly on the east side, where the stronger high was. The wind

[8a] See Pierce, op. cit., fig. 40.

[9] Wexler, Raymond, Friction and the filling up of the hurricane of 1938 over New England. Bull. Amer. Meteorol. Soc., vol. 20, pp. 277–281, September 1939.

velocity was thereby considerably increased on the east side and moderately increased on the west side; around the center the high, rotary velocity continued. The mean wind velocity computed from the combination of the general and the cyclonic gradients on the east of the storm as its center passed across Massachusetts should have been 102 miles an hour if no friction had reduced it. This 102-mile velocity, expected from pressure gradient, was reduced by friction to 80 or 90 miles an hour along exposed coasts and a general average of 60 miles an hour inland. There were, however, occasional puffs of extraordinary velocity, apparently due to the penetration of projectiles of freely moving air from a height of a few thousand feet through the friction-hindered surface layer. These puffs had velocities of more than 100 miles an hour at the time of greatest intensity and may have engendered certain eddies, which still further augmented the local velocity and destructiveness. Such eddies were surmised by Farrar, who described the effects of the tempest of September 23, 1815, in New England as follows:[10]

> It was very violent at places separated by a considerable interval from each other, while the intermediate region suffered much less. Its course through forests in some instances was marked almost as definitely as where trees have been cut down for a road. In these cases it appears to have been a moving vortex and not the rushing forward of the great body of the atmosphere.

Similar features occurred in the recent hurricane, but most of them seem to have been caused by local topographic funneling or by local weakness within a forest that permitted the entry of the destructive wind into the forest along a lane down wind from the initial break.

The same explanation for the violent gusts of a West Indian hurricane is offered by Vazquez.[11] Eddies, at least on a small scale on both sides of the great gusts, were present in the storm of 1938, for the wind direction during the passage of each gust varied considerably. An eyewitness told me that, as the gusts came across a meadow, eddies could be seen plucking and whirling grass into the air. Spray was picked up off the water in the same fashion. There seems to be no evidence of tornadoes in this storm, such as have been observed in one hurricane in Florida and in two or three at Charleston, S. C. No incipient funnel clouds were observed from Blue Hill, though the lowest cloud layer was visible through the mostly rainless air for a distance of several miles. The turbulently mixed

[10] Mem. Amer. Acad. Arts Sci., vol. 4. Quoted by Henry Piddington in The sailor's horn-book for the law of storms, 2d ed., p. 3, London, 1851, and by Channing, loc. cit., p. 5.

[11] Vazquez, P. E., Naturaleza de las rachas ciclonicas in Nueva Orientación en los estudios ciclónicos. Obs. Col. Montserrat, Cienfuegos, Cuba, pp. 58–66, 3 figs., 1940; also, not quite so complete, in Bol. Observatorio Nacl. [de Cuba], ser. 3, vol. 1, pp. 113–127, 1936. Vazquez' diagram of "tornados" in the cyclone is reproduced by P. J. Darlington, Jr., in Quart. Rev. Biol., vol. 13, p. 280, 1938.

lower air (about 1 mile thick) was apparently stable (potential temperature lower) relative to the layers above, a condition adverse to strong convection and the growth of eddies.

Where descending blasts of wind impinged on steep hill slopes and were concentrated by the topographical configuration, their velocity was greatly increased locally, and trees and structures on exposed slopes or shoulders of hills or cliffs or just beyond were blown down or greatly damaged.[11a] At the Blue Hill Observatory, where such gusts might have been expected to show about their maximum increase, velocities of more than 150 miles an hour were almost cer-

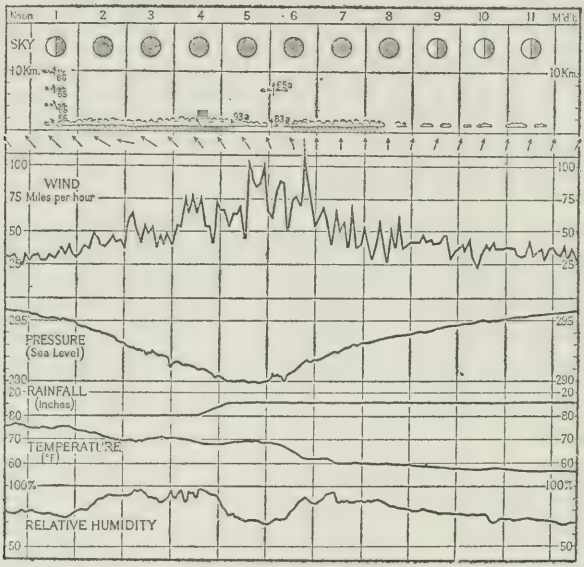


FIGURE 2.—Weather sequence at the Blue Hill Observatory September 21, 1938, noon to midnight, eastern standard time (plotted by H. S. Rice and C. F. Brooks).

The topmost line indicates the hourly cloudiness, except that there was a minor break shortly before 6:00 when the wind was shifting most rapidly from southeast to south. The second line indicates the general nature of the lower clouds (upper clouds could only be seen about 1:00 and 5:40). Numerals and arrows roughly indicate cloud velocity in miles per hour and direction of movement (as on a map). The occurrence of rain is indicated by the slant lines under the clouds.

The third line shows the wind direction by half-hourly intervals. The initial swing from southeast to nearly east occurred as the circular portion of the storm approached; the fairly steady veering from east-southeast to south, as the storm passed on the west. Wind velocity (from a 3-cup anemometer) is shown in miles per hour by 5-minute periods, the maximum having reached 121 between 6:11 and 6:16. Considerable irregularity is evident. The pressure record indicates a rather rapid fall until about 4:30, followed by a period of nearly stationary pressure, reaching a minimum of 29.01 inches at 5:17, then a rapid rise as the center of the storm passed and the cooler air swinging around south of the storm increased the density of the air column. The next line shows the amount of precipitation. Below is temperature, showing a rather marked drop around 6 p. m., as the main cold front arrives. At the bottom is the humidity trace. The air, though still tropical, was appreciably drier than it had been the previous day.

[11a] Further details in Brooks, C. F., The hurricane—Meteorological postscript. Harvard Alumni Bull., vol. 41, pp. 1165–1168, July 7, 1939.

tainly indicated by the record from a 3-cup anemometer. The velocity (corrected by Weather Bureau tables) was 186 miles an hour, with an uncertainty, however, of 30 or 40 miles an hour. At Mount Wachusett also the wind showed a considerably augmented velocity as it flowed over the mountain. Similarly, Mount Washington, even though the storm had weakened somewhat when it reached northern New England, experienced winds with hourly velocities in excess of 118 miles and measured gust velocities of as much as 163 miles an hour, and later, a velocity of about 190 miles an hour surmised from the increase in pressure fluctuations inside the building.[12] The wind was so violent that it blew down a long section of the trestle of the Mount Washington cog railway, including Jacob's Ladder, and damaged half a mile of track and cut curving swaths in the forest beyond.

Along the south coast the wind velocity is reported to have been more than 100 miles an hour at several points from Fall River to New London. It was estimated to have reached 120 miles an hour at the Weather Bureau's airways station on Fishers Island, near New London, after the weather tower had blown down. In Cambridge a velocity of more than 100 miles an hour was recorded 5 times by a bridled anemometer. Gusts of 75 miles or more an hour were recorded 76 times in 4 hours, and 48 of these came in a single hour.

On the west side of the storm the increase in wind velocity owing to the western pressure gradient was moderate and amounted to about 20 miles an hour. Consequently, there was no great damage except by flood from the great rains there. The extreme velocities even on such exposed points as the tops of skyscrapers were not more than 90 miles an hour in New York City, except for the Empire State Building (1,248 feet), where the maximum gust velocity was 120 miles an hour. At Central Park the extreme was 60, and in the Bronx 78.

The hurricane had a central eye of considerable diameter. Over Long Island it extended at least 43 miles from a point west of Brentwood, where for 50 minutes there was "calm," partly without enough wind to blow out a match, to Mattituck, where a calm of 5 minutes was reported. As the eye moved over the Connecticut coast, there was a decrease in wind velocity extending from somewhere west of Fairfield to Saybrook, a distance of 48 miles. The calmest point, or center of rotation of the wind with respect to the earth's surface, was necessarily on the western margin of the inner edge of the vortex, where the rotary velocity southward just balanced the forward velocity northward. The most destructive winds necessarily

[12] Further details in Mount Washington Obs. News Bull. No. 4, pp. 19–20, December 1938.

occurred in the vortex near its eastern inner margin, where the rotary velocity and forward movement coincided. Thus the track of the "center" passed west of New Haven and Hartford, while that of greatest destruction passed northward 50 to 70 miles farther east. How far north the eye lasted I do not know, but Northfield, Vt.—in a deep valley, to be sure—had a light wind for 18 minutes as the direction shifted from northeast to south; and on Mount Whiteface, N. Y.,

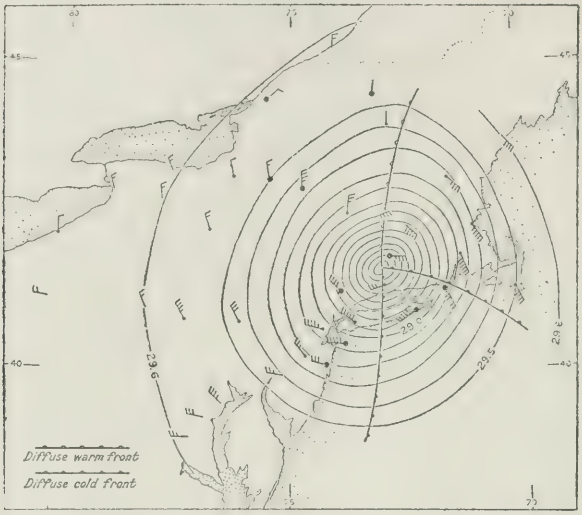


FIGURE 3.—Weather map for September 21, 1938, 4 p. m., eastern standard time. This weather map is based on the airways observations of the U. S. Weather Bureau in the area, kindly sent to the author on request. Each long barb on the wind markers indicates two units on the Beaufort scale; a large dot at the end indicates moderate to heavy rainfall, a small one, light or intermittent rain. The closeness of the isobars suggests the great velocity of the wind. On account of the high wind velocity and great turbulence, the frontal boundaries between different air masses were not at all sharp. The isobars and fronts on this map were drawn by Raymond Wexler. The corresponding map by Pierce (op. cit., fig. 18) bulges the (northern) warm front westward near the center and the eastern cold front northward over Rhode Island, the latter apparently without justification. Pierce did not find a sufficient contrast south of the center to justify him in marking another cold front, as in Wexler's analysis. Nevertheless, he marked a trough of low pressure in this area, marking, apparently, a strong secondary vortex about 100 miles SSW. of the main center and moving northward at the same speed, causing marked changes in pressure, wind direction, and velocity from New Jersey to central Connecticut.

there was a 10-minute calm between hurricane winds from the Northeast and southwest.

As the hurricane entered the trough, it traveled along the general north-south front between the tropical air on the east and the modified polar air, 20° F. cooler, on the west. The rapid rotation began to turn the fronts: the warm front, originally toward the northeast, turned toward the north; the cold front, originally toward the south, turned toward the east as the storm passed over southern New England. As the tropical air passed up the warm-front slope, its fairly

stable lapse rate was increased, and the increased rate resulted in deep convective overturning and extraordinarily heavy rains, amounting to 4 to 6 inches or more over the central and western highlands of New England. These amounts added to the 8 to 11 inches that had fallen in the preceding 4 days gave 5-day totals of as much as 17 inches and resulted in record floods.

The lowest pressure reported from a land station was 27.94, shown at a Coast Guard station, Bellport, on the south shore of Long

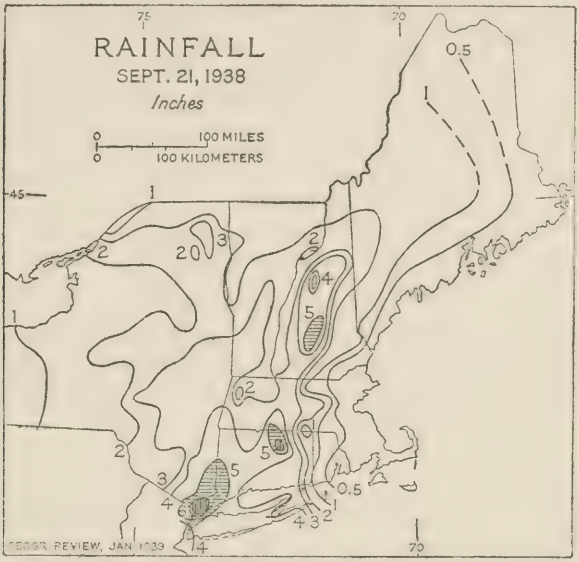


FIGURE 4.—Rainfall map of New England and New York for the 24 hours ending about 7 p. m., September 21, 1938. The maximum rainfalls with the passage of the tropical storm came near the highlands of southeastern New York (Scarsdale, 6.6 inches), the southern portion of the central highlands of New England (Storrs, Conn., 6.2 inches), and in south-central New Hampshire (over 5 inches). The zone of heavy rainfall from north-central Connecticut into New Hampshire was in contrast to the light rainfall of Rhode Island and eastern Massachusetts, because the tropical air was forced to ascend rapidly only where the hurricane winds were rapidly converging near the center, and especially where the tropical air had to ascend over the obstructing polar air along the warm front. The highlands of central New England augmented this ascent.

Island. At New Haven the sea-level pressure fell to 28.11 and at Hartford to 28.04. It seems that the center went closer to Hartford than to New Haven and that there was relatively little filling up of the storm during the first half hour after it struck land. Thereafter the successive low pressures observed at stations in Massachusetts and Vermont were appreciably higher, though the lowest pressures were not represented by the distribution of the observing stations. Though the reduced energy available must be recognized as permitting friction to weaken the storm, the greatly increased drag over the tree-covered hilly to mountainous surface slowed the whirl more rapidly than would have been the case at sea.

HURRICANE HAZARDS IN NEW YORK AND NEW ENGLAND

The conditions under which a West Indian hurricane will strike our North Atlantic coast with full vigor are that (1) the general pressure gradient from east to west must be great throughout the troposphere; (2) the terrain in front of the storm must be well bathed in moist tropical air; and (3) the storm remains over the open sea all the way from the West Indies to its northern landfall. Without the rapid progressive movement the storm would have a chance to lose much of its whirling velocity over the cooler waters north of the Gulf Stream. The presence of moist tropical air over the region helps to prevent a too rapid reduction in energy. Friction with the land is a quick reducer of the velocity of the wind at the surface, causing a decrease in both the deflective effect of the earth's rotation and the centrifugal force of the whirling wind. This results in a considerable flow of air across the isobars into the low-pressure center and, consequently, in a marked reduction of the pressure gradient, which is immediately felt on all sides of the storm. In order to have one of these hurricanes strike the North Atlantic coast from the open sea it is, of course, first necessary that the general winds in the middle levels of the troposphere shall be directed essentially northward or perhaps northwestward, so as to give the storm a movement from the south or from the southeast.

In terms of the hazards to New York City this is a very fortunate circumstance; for not only is New York protected by the New Jersey coast on the one side and by Long Island on the other, but also the chances of the storm's coming from the southeast are slender. Nevertheless, a high storm tide can reach New York, even if surf and the strongest winds from the open ocean cannot. If such a storm tide should coincide with high spring tide and the Hudson in flood, lower Manhattan and its subway entrances might be inundated suddenly. In 1821 the tide rose 13 feet in 1 hour as a hurricane center passed over New York; in 1938 it rose about 6.9 feet in half an hour when the storm center passed into central New England.

Other lessons taught by this catastrophe are: That the North Atlantic States should have a hurricane observing and warning service equal to that of the South; that especial attention should be paid to cloud motions, to be observed and reported whenever visible, as indicators of the direction and velocity of the middle and upper levels of the air stream in which a hurricane may be traveling; that the network of radiometeorograph stations for deep soundings of the temperature and humidity of the atmosphere be extended to include the northeastern States, so that the potential energy available for the storm can be computed and weather maps for levels aloft can be drawn and winds computed when not observable through low

clouds; and that reports be made of the tide levels relative to those predicted and to the occurrence of storm swells all along the coasts where a hurricane might come ashore, by using the valuable rules worked out by Cline for predicting the landfalls of hurricanes in the Gulf States.[13] A teletype, or equivalent intercommunicating system, under the control of the Weather Bureau is required for directing the observers to make the special observations needed at times of threat, for the rapid and sure collection of the observations, and for the dissemination of forecasts of distributing points.

In the year and a half since the hurricane, the Weather Bureau has already made, or is about to make, provision for practically all of these obvious needs and for increased reports from vessels as well. Also, in the restorations of buildings, and even of forests, hurricane hazards have been taken into account. Therefore, when a great hurricane next reaches the North Atlantic States the people will have the warnings adequate to prevent great loss of life, even though the tremendous damage to property resulting from such a catastrophic visitation cannot be materially reduced.

[13] Cline, I. M., Tropical cyclones. New York, 1926; includes relation of changes in storm tides on the coast of the Gulf of Mexico to the center and movement of hurricanes, reprinted from Monthly Weather Rev., vol. 48, pp. 127–146, 1920.

HUMANITY IN GEOLOGICAL PERSPECTIVE[1]

By Herbert L. Hawkins, D. Sc., F. R. S., F. G. S.

It is a curious corollary to our system of education that a large part of the population should be almost completely ignorant of geological science. This ignorance is common to all classes, not least among those who have suffered intensive mental cultivation. Without unduly stressing the sentimental consideration that ordinary people might be expected to take an interest in the nature and history of their mother, we must marvel at the lack of curiosity of those who use and enjoy the material amenities of civilization. In an age of petrol engines and ferroconcrete, an intelligent interest in the nature and origin of essential raw materials would be expected to extend beyond the few whose business it is to locate and exploit them.

A bare catalog of the necessities of life today or at any time in the past, under any form of civilization or none, is but a list of materials that are directly or indirectly the concern of geological research. For geology is the science of the earth and all that it contains, inanimate or animate, past and present. Fuel, metal, stone, water, and soil are necessary to our various activities and for our very lives; so that the practicing geologist (whether called by that name or not) is and must always be at the back of every enterprise.

No intelligent person can fail to realize the immense importance of applied geology in such matters as mining or civil engineering; but the uninitiated may be forgiven for doubting the utility of some branches of geological research. The character and evolution of extinct micro-organisms seems a topic that can serve little useful purpose save to keep some crank out of worse mischief; while the molecular and atomic readjustments of minerals subjected to violent treatment far underground appear suitable to be dismissed as "academic," a word often considered synonymous with "useless." Nevertheless, petroleum companies find it advantageous to employ experts on the evolution of the foraminifera; and the discovery and exploitation of mineral wealth depends on knowledge of the processes involved

[1] The eighth Alexander Pedler lecture, delivered under the auspices of the South-Eastern Union of Scientific Societies at Worthing, June 24, 1938. Reprinted by permission from report of the British Association for the Advancement of Science, 1938.

in its production. There is, indeed, no such thing as "useless knowledge"; for knowledge is a tool ready to the craftsman's hand, always effective if skillfully used.

In addition to, and transcending, the material contribution of geological science to civilization, is the esthetic influence of the study; for geology is a stimulant to the imagination. Without intelligence man is but an unsatisfactory animal; intelligent but unimaginative he is a dangerous nuisance; imaginative and unintelligent he is futile; but with imagination controlled by intelligence he is truly human. The glories of nature, whether expressed in a landscape or a sand grain, are wasted on a mind that fails to respond with intelligent curiosity. There is better and more inspiring entertainment to be derived from the works of nature than was ever provided by the art of man. Boredom and disillusionment, those ravaging diseases that kill body and mind, can never approach a man trained to appreciate his environment. No very profound geological knowledge is needed to transform a country walk from mere exercise of the legs into an adventure of the mind. Everywhere in this world is a happy hunting ground for a geologist. The average expectation of life among geologists is such that it has fostered the superstition that geology, like bowls, is a pastime of senility; it is due to the perpetual interest that keeps life worth living.

My purpose tonight, however, is neither to extol the study of geology as a gateway to long and happy life, nor as the basic factor in the material aspect of modern civilization. I wish to direct your thoughts rather to the reaction on our philosophy of life of such geological facts as can be claimed to be established. Man's place in nature, his whereabouts in time and space, is, and has always been, his fundamental problem. Early and medieval attempts to solve that problem were foredoomed to failure, for next to nothing was known of nature, and philosophical speculation savored of vacuous bombination. We still know very little about the material universe, but we do know something; and our few established data afford a solid basis for theoretical deductions that are as worthy of serious consideration as some of the older speculations are of ridicule.

Most psychologists, and all parents, will agree that a young child, as soon as he acquires independent consciousness, is in his own estimation the center of the universe. All phenomena that he experiences are aimed, benevolently or maliciously, at him and at him only. He is, in his own conceit, the only pebble on the beach. Experience and training will in time tend to modify this attitude; and indeed, if and when wisdom comes, egotism will be banished. But knowledge is usually in advance of wisdom, and there is often a regrettable stage in childish development when budding knowledge is mistaken for

omniscience. This phase can also be modified by experience. After the disappointment and humiliation have subsided, the adolescent is in a position to find his place in the scheme of things, and to adapt himself to it. The clever animal may become transmuted into a man. His success in that sphere may be measured in direct proportion to the reversal of his childish instincts.

It is not surprising that the earliest philosophers, the first thinkers in the childhood of the race, should have fallen into childish errors. Scarcely removed from the supreme egotism of animals, but capable of correlation and imagination, they saw themselves as the ultimate climax of creation, for whose especial accommodation the whole universe was designed. They could not conceive of any reason for the existence of the world apart from themselves; so that, for them, the world and the universe were made expressly for their habitation, scarcely antedating their arrival. By precisely similar reasoning, the only habitable part of the world, perhaps all the world there was, centered around their homes and extended not many days' journey beyond their horizon. Early voyagers must have experienced exceptional thrills from excursions into regions that did not even exist; doubtless their tales were given no more credence than the reports of geologists who described terrestrial events that preceded the creation of the world.

It is surprising to realize that less than 2,000 years ago our predecessors had scarcely any reliable knowledge of world geography, and less of the configuration of the globe. An interesting study could be made of the influence on philosophical ideas of the vast increase in the conception of space that resulted from medieval exploration. Our modern ideas of cosmic space, whether curved or infinite, are in some sense but a sequel to the revolutionary discovery that there was anything of the sort to discover.

Realization of the immensity of geological time is relatively recent, and it is far from universal even today. Whereas a conception of the size, and even of the cosmic relations, of the world is subject to daily experience and confirmation, that of past time is more subtle to obtain. Modern transport and other inventions enable us to span in a day distances greater than early conceptions of the size of the universe; but we are still time-bound by the three score years and ten of our earthly experience. It may be doubted if anyone, even a geologist or a historian, can form a clear idea of the significance of a thousand years of time; while it is probable that the four or five thousand years canonically ascribed to the earth's existence seemed an almost infinite period to those who decided upon it. And yet today we know that an interval of, say, 100,000 years represents an infinitesimal part of world history, and does not cover even the duration of mankind.

We know, thanks to archeological research, of complex human civilizations antedating the official creation of the world; and we know, through geological research, of animals and plants that populated the earth in eras a thousand times more remote. We know, but we cannot truly comprehend.

Although we must stand bewildered before the actual figures of geological time, more hopelessly than before those of cosmic space, there is no serious difficulty in appraising relative time values. A million years may be inconceivable, but they are obviously fewer than ten million or a hundred million. We can mentally dispense with the ciphers, and reduce the totals within the limits of our understanding. So that if we estimate the duration of mankind at 1,000,000 years, and that of the Cenozoic era (the "age of mammals") up to the present at 60,000,000 years, the ratio of 1 to 60 is a true and intelligible expression of the data. Whether we give credence to the estimates of the length of preceding eras or not, we can readily understand that they were collectively vastly longer than the Cenozoic. And who shall say what vistas of time are behind and beyond the mists of the pre-Cambrian? Without pretending to ascribe to geologists an abnormal share of the attributes of Deity, it is within the truth to say that they think in terms of time where "a thousand ages" are lost in the total.

The calculations of astronomers and physicists have, of course, a profound interest for geologists, and we may be gratified if their results accord with ours. But we must be forgiven if we regard them as giving but uncertain confirmation, or negligible denial, of our own deductions. Too often in the past century did the physicists attempt to limit the duration of the world, and of the solar system, within impossibly small scope, basing their conclusions on the elusive and superficially convincing principles of mathematics. Doubtless their arithmetic was beyond cavil; but the premises were inevitably incomplete and even inaccurate. The hoary imposture of the accuracy of the "exact" sciences still deludes mankind, through the wildly illogical belief that a rigidly logical argument must reach a correct result whatever errors may have existed in the premises on which it is based. Nevertheless, however askance we may look at the current theories of astrophysics, we can recognize with satisfaction, that their bearing on time is consistent with the conception of the world's duration deduced from geological facts.

Three considerations that are inspired by our present knowledge of geological history may be emphasized here. In the first place, the human race, though of far greater antiquity than our forebears taught, has existed for a minute fraction of the time during which the world has been essentially like it is today. Indeed, the "human

period" requires the myopic vision of an archeologist; it is too near and too small to focus clearly on a geologist's retina. Secondly, the world was a "going concern," with successive waves of prolific population, for vast periods of time before the appearance of mankind. Thirdly, and perhaps most significantly, throughout the whole sequence of these incalculable ages, physical, chemical, and biological laws have remained the same. A rhythmic orderliness pervades the trivial and ephemeral details of the earth's history—without it all scientific endeavor would be in vain.

This is a very different view from that prevalent but a few generations ago; and since it is, as far as it goes, demonstrably true, the old ideas must be wrong. They served their purpose in the childhood of mankind; but now that we are growing into intelligent adolescents, with a glorious prospect of new truths to be learned, they are out of date and must be put away. It is grievously hard to discard a disproved theory, but much more difficult to get free from the philosophical deductions that sprang from it. When the theory is based on self-esteem, and the philosophy designed to justify conceit, conversion becomes painful in the extreme. Some, blinded by prejudice, employ the childish ruse of denying the truth offhand, in the pathetic hope that truth is destructible. Others, more circumspect but even less respectable, ignore the facts even when they see them, or pretend that they have no bearing on their philosophy of life. Others again, intellectually convinced but emotionally hide-bound, strive to force the old beliefs into the new container.

Most of us believe, and almost all pretend, that the world, and indeed the universe, was devised expressly for our convenience. Perhaps a thief may consider that the trinkets he purloins were made for him to steal; but was that the jeweler's original intention? One can but gasp at the effrontery of a person who considers, for example, that the coal measures were laid down in far-seeing preparation for human needs. If for a moment one grants that preposterously egotistic assumption, what is to be said of the millions of tons of coal that were destroyed by denudation long before their rightful owner was ready to use them? Indeed, when arguments of this sort are employed (and they are usually the stock-in-trade of those most seriously anxious to give reverence where it is due), the result is a dilemma from which blasphemy affords the sole escape. Philosophy is the clothing of truth; a baby's vest is inadequate and indecent on an adolescent.

We must reconcile ourselves, and our philosophies, to the fact that from the world's standpoint we have only just arrived. Although during our brief career we have made an unconscionable mess of parts of its surface, the globe continues to revolve unperturbed, and we

cannot imagine that our disappearance would cause it a passing tremor. To those who have grown up in the belief that the world was made solely for their occupation and benefit, this conclusion seems humiliating; but only the conceited can experience humiliation. Moreover, the third scriptural criterion for a satisfactory and moral life involves humility. There can be no incentive to progress for those who think that they have already arrived, and there is no prospect but a fall for the arrogant. But to those who are not blinded by conceit there is stimulation in the thought that they are playing a part, however humble, in a vast drama; and elation in the knowledge that they alone, of the actors, can be more than puppets in the show.

If the first two of our considerations tend to induce humility, the third surely inspires confidence. The constancy of natural laws, the reiteration of cause and effect, the simplicity of the outline of history, show that there are some principles at least in which we can trust. There is an orderliness in nature that we can appreciate without knowing its origin or aim. One has but to read some of the cosmogonies of the last few centuries, when the catastrophic school was trying to compress the gallon of geological facts into the pint pot of canonical time, to realize how profoundly our views are altered. These earnest attempts to reconcile fiction with truth led to a conception of the world staggering from one supernatural cataclysm to another, and make ludicrous reading today. They evoke a picture of a Creator learning by trial and error, with no set plan and very little patience—surely the butt of ribaldry rather than the inspirer of reverence. There could be no security under so fickle a tyrant, and no point in trying to understand a policy that might be reversed at any time.

Just laws must bind the legislator no less than his subjects; and it is a heartening thought to realize that even in Cambrian times the sun shone and the rain fell with the same sort of effects as they produce today. It gives confidence to know that, come what may, effect follows cause as day follows night, and that in a world of seeming change and decay there are principles and processes that are eternal. In the material world at least we can know where we are, and what to expect. There are laws that neither time nor circumstance can alter. We can discover their gist, learn to obey them, and so acquire power beyond imagination; and on the other hand we can ignore them or defy them, and perish.

The geological record shows that we have but a small, perhaps transient, part to play in the world drama; but it also reveals the grandeur of the theater and the impartiality of the management. It induces humility, but gives security. The establishment we have so recently entered is soundly constructed and consistently managed; with reasonable observation we can learn the way to our own rooms

and the sure results of our actions. But valuable and salutary as this knowledge may be, it leaves us completely at the mercy of our environment, like passengers in a train going they know not whither with almost ominous smoothness. Our surroundings are impersonal, insensitive, and inevitable; it is for us to make the best we can of them. And here another aspect of geological history, paleontology, is available to give warning and advice. The story of life through the ages of the earth's history touches us more nearly than does that of the inanimate fabric; for we are living creatures, and our bodily lives are held on the same terms as those of the rest of the animate world.

Before attempting to discuss the influence of the paleontological record on our own case, it is necessary to meet certain objections that may be raised. The same childish conceit that supposes the universe to be a playground made for mankind alone automatically believes that man is so far superior to all other creatures that the episodes of their obscure lives have no bearing on the problems of his exalted existence. It is of course true that man has certain attributes and capacities that are scarcely developed among other animals; but so have all other types, else how could we distinguish and classify them?

For convenience we may admit that a man consists of two parts, commonly called body and soul, and that these two parts are largely antithetic. All respectable religions have always stressed the conflict between the carnal and the spiritual; and yet many most earnest enthusiasts insist that their enemy, the body, must be as peculiar and sacred as their friend the soul. Confusion of thought such as this is not only strange, but disastrous, for it is the beginning and end of materialism. The human body, in its anatomical and physiological characters, is an animal's body; as such it is strictly comparable with that of any other animal, and subject to the same laws. Anyone who believes otherwise, and lives in accordance with his beliefs, will be dead within an hour.

Such evidence as is available to show the history of living creatures during the course of geological time will therefore have at least a partial bearing on the problems of our own lives. It will be apt for comparison with our bodily and racial lives, and our reactions to our physical environment, whatever complications may be introduced by our special human attributes.

A comprehensive survey of the paleontological record shows conclusively that there, as in the physical history of the earth, inviolable laws are in continuous operation. Paramount among these laws is that of cause and effect; which, in its biological aspect, is called the law of evolution.

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In many cases, and for various reasons, our apprehension of the causes of evolutionary change is far less complete than in the case of physical processes; but the constant repetition of similar effects gives presumptive evidence of oft-recurring cause. The chief difficulty in appraising the determinants of evolution lies in the dual nature of life, expressed in the legacy of heredity and the impact of environment. Opinions differ widely as to the relative importance of these twin influences, but there is no room for doubt that both exist, and that they may often prove incompatible.

An unfortunate but inevitable weakness of paleontological evidence enables it to show very little of the early history of groups of organisms, although its record of their decline and fall is often clearly displayed. We are far from knowing how or why new types appear; but on the other hand we have plentiful illustration of how they disappear, and convincing indication as to the way in which nemesis overtakes them.

The record of evolution is, in essentials, the same for all groups of organisms. Indeed, it is the same when expressed in the changes that befall the several organs of which organisms are built. Phylogeny and morphogeny are mutually dependent, for the whole, though greater than the parts, consists of them and is directly affected by their condition. Hyperbolic though it may sound, it is a bare fact of experience that the life story of an individual, or of a single cell in its body, is a précis of that of a phylum, or of any taxonomic grade. Families and orders, like species and individuals, may possess the contrasted qualities of "perennials" or "annuals"; but the general trend of their lives is the same. They have their youth, a stage of growth and adaptation; their maturity, when equilibrium has been attained; and their senility, when persistent development beyond perfection leads to decline and death.

In the youthful stage groups or individuals are plastic, producing much diversity by the reaction of their intrinsic vitality with the molding influence of environment. In the senile stage their characters have become stereotyped, and their reaction to an ever changing environment is extinction. The same inexorable range of variation in physical surroundings acts as a tonic to the young and a poison to the old. For life is a competition between the mysterious quality called "vitality" and the insensitive environment that encompasses it. The struggle is exhilarating, creative, and usually successful, in youth; but old age fights a losing battle. The secret of perpetual youth is no mystery, for all that is needed is perpetual plasticity, giving ready adaptation to environment. But in the nature of things this is impossible. It is true that simple forms of life can adjust themselves and their needs to varying conditions more readily than more complex forms; they have a greater expectation of racial life; but there is a term to their duration. Life itself, transmitted from

one generation to another, may be everlasting; but all living things are mortal.

This sounds like a somewhat morbid summary of the course of an ordinary human life; but actually it is a description of the evolution of every large or small group of organisms of which we have adequate paleontological knowledge.

There are two harmonies essential for successful living, one internal and the other external; both must be kept consonant. The several organs of an organism must maintain their proper proportions, and the organism as a whole must conform to its surroundings. Internal discord, due to the modulation of one ingredient independently of the rest, cannot fail to produce inefficiency and final collapse; while external discord brings the individual into mortal conflict with an invincible opponent. One or the other of these disasters is in store for every living thing, be it a cell, a body, a race, or a species. To be alive is to be changing, and there is a limit to the range of possible harmonies.

Recognition of the orderliness of animate nature, and of the inevitable sequence of change, decay, and replacement, does not engender optimism when we think of ourselves, our institutions, and our species. A complicated mammalian mechanism with an overdeveloped nervous system seems like a diagnosis of a very short-lived race.

If we despairingly claim that our wits have enabled us to reduce the risks of environment, the records of our history are open to show that the internal dangers develop none the less. Diseases of disproportionate development, such as cancer, attack individuals; and civilizations crumble through overcomplexity and dissension. Our cleverness may make our success spectacular, but it speeds on the ensuing collapse.

By virtue of our overdeveloped intelligence we accelerate the processes of evolution, especially in our social relations; and whatever hope evolution may hold for the unborn, a tomb is all that it can offer to the living. The history of the decline and fall of empires makes familiar reading for a paleontologist; it illustrates in a condensed and diagrammatic form the late phases of evolution in other creatures that are the normal subjects of his study. Regrettable though it may be, the human animal seems to a paleontologist superior to a dinosaur or an ammonite merely in the speed with which it rushes toward extinction.

This is a tragic outlook; but there is nothing unfamiliar about it. All individuals realize, when they choose to think, that they are not immortal; every philosophy and religion lays emphasis on the transient nature of "man's earthly hopes." It is not only the paleontologist who knows that the prize awaiting the winners in the struggle for existence is death. Nor need we be morbid in our outlook; a man

who has made his will can still enjoy life. "The play's the thing," not to be spoilt by regrets that the actors will not hold the stage forever. But whether or not we can derive comfort from such considerations, the fact remains that all available evidence, paleontological and historical, racial and personal, indicates the inevitable doom of man the animal, and of all his works.

Must we then reconcile ourselves to the belief that we are such stuff as paleontological collections are made of, and that in the geologically near future a few fossil relics will be all that remains of our species? A creed so desperate would demand extinction as an escape from a farcically hopeless existence. Before finally abandoning ourselves to utter pessimism, we may try to review our position from another angle.

Once, very long ago, even as a geologist reckons time, a strange thing happened. We do not know why or how; but a certain combination of substances acquired the quality that we call life. In many ways the first organisms, doubtless unicellular and microscopic, defied the ordinary laws of physical nature. Especially was this the case in their capacity for sexual reproduction and its consequent succession of everchanging individuality; in other words, in their quality of evolution. The organic world, surrounded, influenced, and in no small measure controlled, by the inorganic, started on an adventure that led it ever further from the mechanical principles of insensate forces. Today that same "life," spread among a myriad of individuals, is still flourishing, and shows no signs of decline. It is an important, though superficial, part of the economy of the globe. Its more progressive exponents, elaborating their structural and mechanical diversities, have acquired an enhanced sensitiveness that has become concentrated into a definite nervous system, and has gradually attained the faculty of intelligence. Being mammals ourselves, we can recognize in our fellow mammals mental capacity and consequent behavior that appeal to us as comparable with our own; it is not possible to appreciate the mentality of creatures utterly unlike ourselves, even if such mentality exists. Nevertheless, it seems evident that reception of sensations and response to them become more acute and intelligent with improving brain structure. Increasing faculties of locomotion stimulate perception, and life becomes less automatic and more emotional. The brain comes to dominate the organism.

The earliest forms of life must have striven against their physical surroundings, for life is an irritating alien in the inorganic world. But when, by virtue of the faculty of multiplication, living things came to exist in great quantity and congestion, internecine competition was added to environmental problems, and the complicated anarchy of the "struggle for existence" began. Structural advantages, or (in later stages) mental superiority, help to bring success to

their possessors; but the struggle is ultimately unavailing. For although the winners may crush, and perhaps even exterminate, the losers in any particular rivalry, the factors that gave them victory ensure their collapse. Unobtrusive types endure, but aggressive and domineering types achieve success and disaster in direct proportion. We can liken the course of evolution to the use of a cylinder of gas. If the gas is allowed to escape slowly under control, it may burn steadily, giving a feeble light, for a long time; if it all ignites at once, there is a brilliant flash, a crash, and then darkness. Such were the records of *Lingula* and *Productus*, or of the turtles and dinosaurs.

Mental acumen is a better means to success than mere structural advantage. The rapid rise and fall of hosts of mammalian types, contrasting as it does with the considerable stability of the invertebrate fauna during the Cenozoic era, seems a clear illustration of the paradox of the struggle for existence, where the prize is death.

And so once more we reach the depressing view of the human species, surely the most spectacular and record-breaking winners yet evolved, hastening toward the reward of victory. Insofar as it has entered the lists, matching its capacity for selfish greed against the individualism of other animals or of its fellows, the human race is bound by the rules of the competition, and the prize is within its grasp. Man is a supremely successful animal; such success, whether involving murder or not, is the precursor of suicide.

There can be no doubt that the introduction of life marked a crisis in the earth's history. Perhaps its significance can be best expressed by the suggestion that to the eternal changelessness of physical laws there was added the eternal changefulness of organic evolution. Bound by the insensitive chains of material environment, living organisms possessed a sort of individuality of which they became increasingly conscious with the improvement of their nervous mechanism. Sensation and reaction were limited to physical and material phenomena, and so were ultimately subject to the inexorable rules that propelled their possessors from birth to death.

But the nervous mechanism of mankind can transcend the sensuality of the animal brain. It is perhaps not too extravagant to claim that the faculty of imagination is an acquisition as far advanced beyond that of sensitiveness as life is beyond nonlife. When an abstract conception was formulated for the first time, a man was born, and a marvelous new quality introduced into the world. For imagination, though expressed through the medium of material and ephemeral apparatus, can break the bonds of physical restraint, finding freedom and immortality among the eternal verities. Imagination is the gateway to wisdom, and an antidote to cleverness.

The growth of the imaginative faculty has produced, or perhaps can produce, a remarkable revolution; for its most obvious result has

been a complete inversion of the technique of life. The quality of a man is measured by his recognition and exposition of such qualities as honesty, sympathy, and unselfishness, rather than by his skill in ruthless self-aggrandizement. Truth, chivalry, and kindness are inconsistent with the struggle for existence; but they are recognized as desirable attributes even by those underdeveloped minds that class them as impracticable ideals. A "realist," who boasts that he "faces facts," denies his humanity and takes pride in beastliness; an "idealist," who faces noble thoughts, is a man.

The human race is very young, and few of its members have as yet shown enough precocity to visualize, let alone to attain, the ideal that is humanity. To mankind in the mass a real man is a sort of "foreign devil," to be treated as animals treat aliens in their preserves. Prophets are stoned by their generation, even though they are sentimentally canonized by the next. Philosophers are "such stuff as dreams are made on," and therefore unintelligible and irritating to animals, however clever. But men can learn; their capacity for appreciating wisdom shows that its acquisition is not beyond their powers. And wisdom, which makes men human, is better than the rubies of material success that may leave him bestial.

The contrast between the attitude of imaginative insight and that of animal instinct is nowhere more clearly seen than in the realm of ethics and morality. Every action that savors of the struggle for existence is a sin, and every effort in the reverse direction is a virtue. There could be no clearer illustration of the power of the imagination to see beyond knowledge than the pronouncement that "the wages of sin is death," made centuries before the laws of evolution were suspected.

The exponents of religion, in spite of the Laodicean spirit of compromise that lessens their effectiveness, give more than lip service to the creed that man should be different from the other animals. A multitude of organizations directly or indirectly sponsored by the churches attempt to translate this pious belief into practical service. Science, especially in its medical branches, caters to all sorts and conditions of men with selfless devotion. Some enactments of legislation definitely encourage humanity as an alternative to brutality, and extol principles above opportunism. Perhaps some day even financiers and statesmen may discover that their choice is between the Mammon of deceit and animal avarice and the God of truth and human sympathy, and that there is no middle course. Until then they will continue to lead their dependents and subjects along the well-worn track that opens before all the "beasts that perish."

The alternative is a great adventure, whose end none can foresee, along the trail blazed by martyred pioneers who have had the courage to be men.

GEOLOGIC EXHIBITS IN THE NATIONAL ZOOLOGICAL PARK

By R. S. Bassler

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[With 8 plates]

INTRODUCTION

Geologic features illustrated by exhibits in the several buildings of the United States National Museum and the Department of the Interior are well known to Washington visitors, but few are aware of the many out-of-doors rock displays in the vicinity of the Nation's Capital, especially those in the Zoological Park under the supervision of the Smithsonian Institution. In a previous article, "A Geologist's Paradise," [1] the general geology of Washington and its environs was discussed, but that part of Rock Creek Park occupied by the Zoo offers so many special points of geologic interest as to make this comparatively small area worthy of a more detailed description. The exhibits here are in almost all cases natural *outcrops*,[2] which, however, in some instances have been better exposed by man or protected against destruction.

A large part of Rock Creek Park is occupied by a typical V-shaped *stream valley* cut in the low plateau upon which the higher northwestern part of Washington is built. Here, the greatly folded hard rocks representing the oldest recognizable periods of earth history are well exposed by *stream erosion*, but the whole region, formerly the site of high mountains, the older Appalachians, as indicated by the tilted strata, has been so completely planed off during the course of geologic time that it is a plain surface, although elevated now about 400 feet above sea level. This is the *Piedmont Plateau*, so called because of its position at the foot of the Blue Ridge Mountains to the west. Like the Blue Ridge, the Piedmont is an example of the *physiographic provinces*, the large natural geographic divisions of our country that result from their geologic structure and the

[1] Smithsonian Ann. Rep. for 1933, pp. 327–332, 1935.

[2] The italicized words throughout this sketch call attention to the various geologic features illustrated near the entrances or within the Zoo Park. An alphabetical list of these items closes this article.

weathering to which they have been subjected. The Zoological Park is located near the *fall line* marking the eastern edge of this plateau, where the hard, less soluble Piedmont rocks are overlapped by the unconsolidated, easily eroded sands and gravels of the *coastal plain* to the east, the *Atlantic Coast Plain* province, made up of practically horizontal *sediments* deposited mainly by the sea. Slight uplift along the fall line in comparatively recent time, geologically speaking, has sufficiently elevated the area to cause vigorous stream action resulting in deep valleys such as that of Rock Creek, although in its lower reaches the stream descends almost to sea level, the ultimate *base level* of erosion. As a result of this stream cutting, here are many exposures of the underlying rocks. These, acted upon by the weather and other surface phenomena, illustrate particularly the features of *physical geology*, that part of the science dealing with the forces operating on the outer part of the earth and the changes produced by them. *Historical geology*, which is concerned more with the sediments deposited by water and wind, and their contained record of life of the past in the form of *fossils*, may also be studied here but not under such exceptional conditions.

The logical student, in considering the features of physical geology, commences with the cooled crust of the earth formed of the once molten *igneous rocks*. He learns that when the earth's temperature became low enough for moisture to condense and fall as rain (*meteoric water*), *weathering* of these igneous rocks ensued by decomposition through solution and chemical means. This was continued through disintegration of the rocks with the aid of physical agents, such as the wind and variations in temperature, both processes resulting in the surface configuration and the formation of soils. Part of the rain, the *run-off*, remained at the surface and as running water on its way to lower levels carved out valleys, while the rest sank into the earth as *ground water* to perform the geologic work of solution, cementation, mineral precipitation, and the like. Ultimately, both the run-off and ground water reached the ocean or other bodies of water where the materials dissolved or eroded from the older rocks were laid down in horizontal parallel layers or *strata* of *sedimentary rocks* by the process of *stratification*. Such rocks are known as *marine deposits* if deposited under the sea, or *fresh-water deposits* if in lakes or streams. In the course of time the sedimentary rocks as well as the igneous rocks sometimes were changed, usually by pressure and heat, into another form called *metamorphic rocks*, for example, the granites into gneiss, and the clays and shales into slates and schists. Sometimes all three types of rocks become so folded, or fractured, or elevated by the processes classified under *diastrophism*, that with uplift, plateaus resulted, or with uplift or folding followed

by erosion, mountains were formed, or, finally, with continued erosion all elevated areas were again reduced nearly to base level to form a *peneplane.*

HARVARD STREET GEOLOGY

Many geologic items may be studied by the actual outcrops in the immediate vicinity of the Harvard Street entrance as noted in the following short trip through the eastern part of the Zoo. At Sixteenth and Harvard Streets, the more or less plain surface of the Piedmont province, once worn down to base level or peneplaned, as evidenced by its *even sky line*, and later elevated, is now a marked feature. From here one descends Harvard Street into the stream valley of Rock Creek. The artificial grassed terraces on the right of the street cover former rock outcrops, one of which, on the slope opposite Eighteenth Street (pl. 1, fig. 1), has been left exposed as an outdoor exhibit. Here, in a circular area protected by a low hedge and a row of granite blocks, is seen a small section of the earth's crust illustrating a *geologic section* including a great geologic *unconformity* of the *angular* type. The ancient pre-Cambrian *schists* of thin, compressed micaceous layers representing perhaps the oldest rock formation of the District are noted standing on end. Overlying these are horizontal beds of stratified sediments, consisting of *sand*, *gravel*, *pebbles*, *cobbles*, and *boulders*, these being classified by size from minute sand particles to 10-inch or larger boulders, all representing *clastic* material so called because broken up from former rock formations. The schists belong to the Proterozoic, the second of the great eras of geologic time, and the overlying sand and boulder beds to the Mesozoic, the fourth era. The line of contact separating the two thus represents a great hiatus in earth history during which, particularly in the Appalachian region to the west, as shown by measurements, over 25 miles of sediments were laid down in the oceans of the long intervening Paleozoic era. The pre-Cambrian age of the schists is determined by the occurrence above them to the west of the earliest Paleozoic Lower Cambrian sandstones changed into *quartzites*, and fossil plants such as cycads and occasionally bones of dinosaurs of Upper Mesozoic Cretaceous time date the boulder beds. The latter, often called the *dinosaur gravels*, frequently start with a conspicuous *basal conglomerate* formed of boulders cemented together and representing the initial deposit of the Cretaceous sands on the schist. This same geologic section when better exposed in former years (pl. 1, fig. 2) showed other geologic features characteristic of initial deposits, such as the occurrence of a thin bed of bog iron ore, composed of the impure hydroxide *limonite*, and sometimes the carbonate *siderite*. These ore beds occur in depressions in the eroded, undulating surface of the upturned schists, where they

formed, as today, in low flats or swamps of that time. Sometimes they are thick enough to have been of economic importance in the early history of our country. Occasional clay balls, sometimes several feet in diameter, occurring in the sand layers above, indicate probably the course of ancient waterways and today are a fertile source of fossil leaf impressions. Fragments and sometimes entire trunks of *petrified trees* may also be found in sandy layers. These trees are true *petrifactions*, as the original wood structure has been replaced by mineral matter which in this case is silica. More frequently the tree trunks have been changed into brown coal and jet, the black compact variety which frequently takes a polish. Some of the pebbles and boulders contain the *guide fossils* of Silurian and Devonian strata now outcropping in the Appalachians, thus showing their origin. In most cases, however, the boulders are of quartz from the many veins exposed on the Piedmont. In these fossiliferous boulders the fossils occur as *molds* and *casts*, the first referring to the hollow imprint of the organism and the latter when this has been filled subsequently with mineral material.

ENTRANCE GATES

The Harvard Street entrance to the Zoo (pl. 2) is now close at hand with its gates, a favorite place of assembly and study for visiting groups of university students. The stone pillars which support the gates, when rebuilt in 1932, were constructed of hand-trimmed blocks of the three main rock types, selected as a visible demonstration of the classification of rocks. Furthermore, slabs of each type have been placed in both vertical and horizontal positions in order to show the varying effects of weathering under these different conditions. The adverse effect upon the slabs placed vertically interests the students particularly, for they take delight in prying off slivers of rock which have been loosened at the surface by the two processes of alternate heating and cooling, and freezing and thawing (*mechanical disintegration*). Weathering by solution (*chemical decomposition*) is also evident in many of the slabs where in a few years' time the hard rock is softened by rain water which dissolves away the cementing material or reduces the feldspar in the granite to clay. Sedimentary strata are so poorly represented in the Zoological Park that there is little opportunity to study them in natural outcrop, but a few varieties are included in these pillars. The capstone (6) is a sedimentary rock of *continental deposits*, mainly wind-blown sands, the grains rounded by *abrasion* and consolidated by cementation into solid cross-bedded layers of red to brown *sandstone*. A *marine sandstone* made up of angular grains deposited under the sea, where the buoyancy of the water prevents

such rounding, is shown in the light blue blocks (2); a sandstone formed on an ancient sea beach is the yellow material (5) illustrating stratification and closely arranged *ripple marks*. The intrusive igneous rocks are represented by the blocks of coarse-grained granites composed of the *essential minerals*, quartz and *feldspar*, with small fragments of *accessory minerals*, white *muscovite mica* and black *biotite mica* (3). Metamorphic rocks originating from both igneous and sedimentary rocks are present in the column, one (1) being micaceous schist with occasional pebbles, the latter indicating their sedimentary origin, and another (4) thin-banded gneiss derived from the metamorphism of granite.

ROCK CREEK AND VICINITY

As we pass through the Harvard Street gates, Rock Creek comes into view, with many evidences of the phenomena of running water and atmospheric erosion, as well as the deposition of sediments. Most of the exhibits in the park are of natural origin, but by blasting away the rocks and in other ways some of them have been rendered more conspicuous. *Springs* bubble forth here and there, arising either in the porous sedimentary beds at the top of the hills or in the joint planes of the igneous rocks, which thus serve as water bearers (*aquifers*). Here and there in protected areas in the stream, gelatinous masses of *diatoms* may be found, their remains in the muddy bottom recalling the diatomaceous earth found abundantly on the coastal plain around Washington. The subjects of sedimentation and sedimentary rocks may be studied on the plain to the left at the base of the cliff recently containing the bear pits (fig. 1, *P*). Here, Rock Creek in its annual flood periods, as seen in the outcropping edges along the stream banks, has deposited in horizontal layers alternating strata of sand, *silt*, and *clay*, the last sometimes compressed into *shale*. All these various forms of stream sediments are called *alluvium*, and the resulting plain, an *alluvial plain*. The sandy layers when examined under a lens are mainly composed of angular fragments of quartz, indicative of their deposition in water which, buoying them up, did not permit much wear. An occasional layer does contain rounded grains showing origin by wind distribution, in this case forming an *eolian sandstone*. The stream-borne material of this plain mixed with the leafy mold of present-day trees is sufficiently fertile to be classified as a *transported soil*. This small section of stratified rocks also shows several thin beds of vegetation composed of leaves and twigs representing the annual deposit of the nearby trees. These layers now slowly being compressed into *peat*, and this, with the pressure of future years, into *coal*, are separated by sand strata marking the intervening coarse deposits of

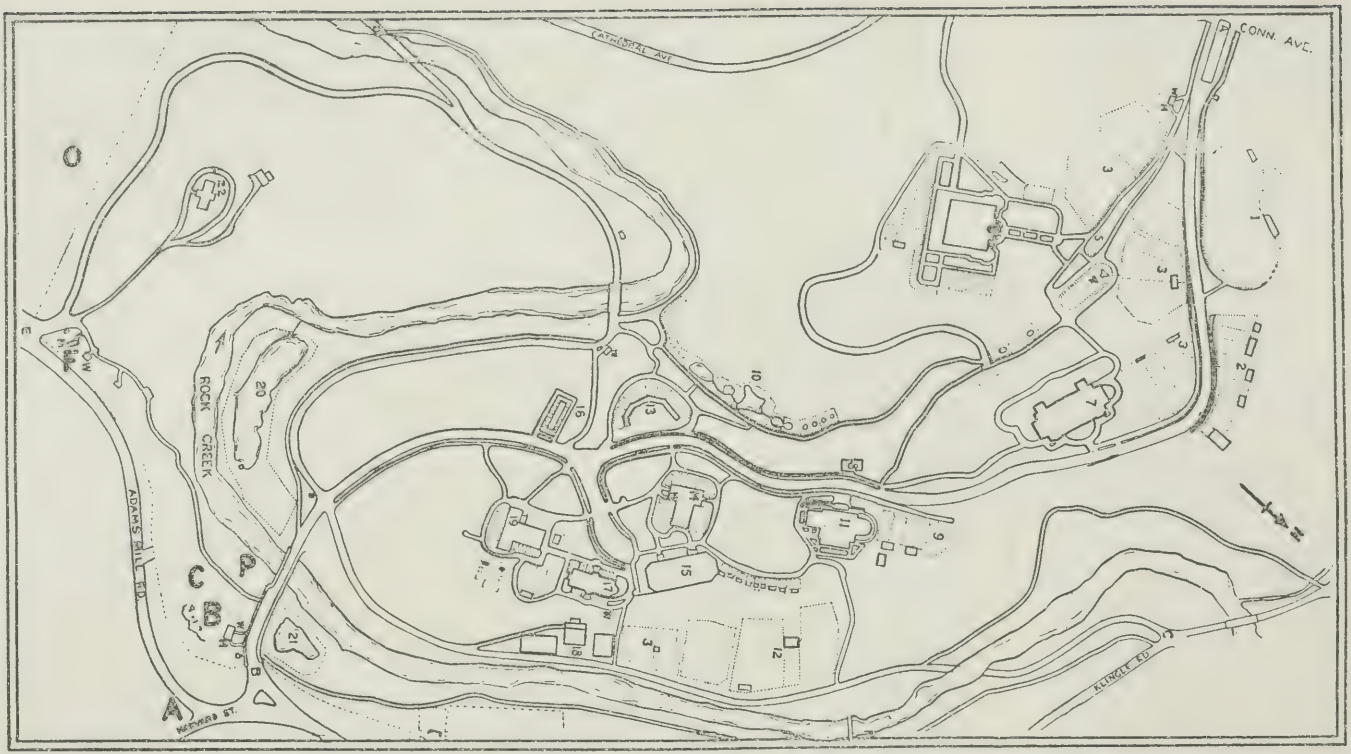


FIGURE 1.—Sketch map of eastern part of Zoo. (1) Director's office; (3) lion house; (4) monkey house; (5) reptile house; (13) wild dogs; (14) bears; (15) pelican pond; (*A*) Adams Mill Road outcrop; (*B*) bear pit exposure; (*C*) schist cliffs; (*F*) fault; (*O*) pre-Cambrian-Cretaceous contact; (*P*) alluvial plain.

winter and spring floods. Land shells and plants occur as fossils in some of the beds and give further evidence of their origin as fresh-water deposits. They also show the very recent age of the strata, since the same species of shells may be found in the present-day creek and the leaves belong to the trees now growing on the plain. These strata constitute a *geologic formation*, since they are a mappable unit formed in the same period of time and hold the same assemblage of species of plants (*flora*) and animals (*fauna*). These layers have a wide enough extent throughout the park to illustrate *correlation of strata* from place to place by fossils, by noting that the same stratum throughout the area contains the same assemblage of species.

A slightly developed ridge along the stream border of this plain illustrates a *levee*. Similar to those of large size and considerable height along the Mississippi and other rivers, this one was formed by the material dropped when the swiftly flowing current at flood time able to carry much mud, sand, and gravel in suspension, struck the still waters of the flood area which no longer had this power. When tributaries enter Rock Creek, *deltas* on a small scale may sometimes be formed. Near the edges of the stream are seen miniature *sand bars*, due to change or slowing down of the current with consequent deposition as in the case of the levees. Occasionally, the flooded stream leaves a mud layer on the plain, which, upon drying, contracts, causing *sun cracks* outlining polygonal areas with upturned edges. These may be broken up and scattered over the plain by *wind action*, forming still another type of continental deposit similar to *loess*. From this alluvial or *flood plain*, built up by stream deposits, the Piedmont Plateau, a plain worn smooth by erosion, can be seen capping the surrounding hills, and not far to the east is the Atlantic Coast Plain, an uplifted sea beach of horizontal marine sediments, these representing the three important types of flat lands classified under *plains*. *Potholes* are occasionally seen in the hard rock stream bed where crevices in the granite or other solid rock contained imprisoned pebbles which, whirled round and round by water, wore out circular areas by abrasion. Above, along the stream valley, are *terraces* of sand and pebbles representing stream deposits of former times accumulated when their waters flowed at higher levels. Near the stream is a lake for the waterfowl (fig. 1, *15*) where the *deposition in lakes* by water is shown to be more active than erosion as the bottom rapidly fills with sediment.

Upstream, beyond the Zoo grounds, Rock Creek develops *falls and rapids* as it tumbles over the granite outcrops and boulders. The old bear pits (fig. 1, *B*, and pl. 3, fig. 1) at the foot of the cliff on

the eastern edge of this flood plain, and the extension of the cliff to the south show the downward extension and hard rock phase of the weathered outcrops described later as exposed along Adams Mill Road (fig. 1, *A*, and pl. 8). The bear pits were built in the granite by the removal of a few of the rectangular *joint blocks* formed by twisting of the earth's crust, the cavities thus affording an idea of their size, shape, and position. The hard granite here is cut by thin *veins* of quartz sometimes crisscrossing each other. Metamorphism through pressure and heat has changed some of the layers into *gneiss* with its minerals compressed into thin parallel bands. At the top of the outcrop, weathering from the surface waters becomes more evident, and with the removal of the soluble feldspar the quartz grains and mica flakes become loosened, although the rock still retains its jointed structure. At the very top of this outcrop along the edge of the Zoo on Adams Mill Road the disintegration has become complete with the formation of a residual soil of sand and mica flakes mixed with present-day vegetable matter. On either side of this granitic *igneous intrusion* the rock formation changes to highly foliated, hard layers of dark-colored *mica schist* speckled with iron *pyrite* crystals and sparkling in the sun upon fresh fracture. The *schistosity* of the rock, due to the parallel arrangement of the particles because of the enormous pressure it has undergone, and the bedding planes of the original sediments possibly coincide in this area; at any rate, the mica schist outcrops here have the aspect of an upfold or *anticline* overturned to the northwest. Mica schist outcrops continue for some distance to the south (fig. 1, *C*), first as highly tilted strata representing a compressed fold, and then with less inclined strata in the form of a low downfold or *syncline*. Here, as in the granite, fractures in the rock of various length and thickness have been filled with *vein quartz* which weathers so slowly that it stands out above the general surface; some of these are *auriferous quartz veins*, as rarely small particles of gold can be seen intertwined with the quartz. Through weathering in the course of the ages such veins have contributed enough *gold* to the stream sands to make *placer mining* possible if not profitable, as a slight color of gold can be obtained by panning the gravels of certain streams in this area. Elsewhere in the park these quartz veins sometimes attain considerable thickness and because of their slow disintegration remain well-defined hills. At still other places where the schist comes in contact with either granite or gneiss, minerals are developed through *contact metamorphism*, *garnets* being found usually in such circumstances. Again, here and there former deep fractures in the earth's crust have been filled by the intrusion of *magma*, deeply buried, molten

igneous material, cooling slowly into *pegmatite dikes* in which quartz, mica, and feldspar, with crystals larger than in ordinary granite, are the prevailing minerals.

Along the base of this cliff quite different phenomena are in evidence. *Temperature changes* resulting from the alternate heating and cooling of the rocks on the face of the cliff due to the hot sun of the day and the cold of the night cause fragments of rocks to be splintered off as the first stages of clastic material and to fall to the bottom, where they accumulate as a *talus slope* at a definite angle, the *angle of rest*. In the winter, *frost action* in the form of freezing and thawing of water percolating through the rocks gives the same results. In a ravine the fragments may slide to the base by gravity, forming a *rock glacier*. This slope, furthermore, often shows *creep of soil*, a geologic phenomenon of considerable importance when developed on a large scale. In this process, it will be remembered that water seeping into the soil freezes and the resulting expanded ice crystals raise rock particles up on edge. Then, with melting, these particles drop again but slide a little farther down the slope. Still another example of weathering may be noted along such a slope where pebbles or rock fragments cap a series of pillars of softer material giving a castellated effect. In such a case the capstone protects the soil particles underneath it from being washed away by the rain, imitating, on a small scale, the *badlands* scenery of the west. Here, also, on the face of the cliff the *action of life on rocks* in the process of weathering is shown by the roots of trees forcing their way between the layers and following the joint planes at high angles. However, water is the more important factor here because in percolating along the joint planes it disintegrates the rocks by solution.

Turning now to nearby Rock Creek, the natural exposures illustrate particularly weathering by *erosion*. The creek bed itself is sometimes covered with large angular blocks of granite torn from their native ledges by the force of the water and borne some distance with the volume and strength of the current. When these fragments drag along the stream bottom, they wear the underlying rocks by actual scratching or abrasion, specifically called *corrasion* (pl. 4, fig. 2). Here occurs still another type of boulders, usually much smaller, which show from their composition that they have been derived in other ways or from far-away sources. Most of those in the stream bed today were washed out from the nearby gravels of the Potomac formation or from the more recently deposited Pliocene and Pleistocene gravels, but all in turn were previously derived from older formations outcropping to the west and deposited by streams of ancient times. Pebbles of *smoky quartz*, *amethyst*, *milky quartz*,

jasper, *rose quartz*, yellow (*citrine*) quartz, and *chalcedony* from veins in the igneous rocks, and several types of the more insoluble rocks of the Piedmont Plateau among these afford a field for the mineral collector. Boulders of the sedimentary formations are represented by quartzite with *Scolithus* worm tubes from the Lower Cambrian of the Blue Ridge, iron-stained sandstone of the Silurian Clinton strata of the Appalachian Valley, *saccharoidal sandstone* from which glass is now made, and *flints* and *cherts* with characteristic Devonian fossils (trilobites, corals, etc.), from the Allegheny Mountains. Limestones and other soluble rocks, even including the granites and gneisses, are absent because, although originally present, they have been dissolved away long ago. The water thus has another erosional power through its ability to dissolve rocks by the process called *corrosion*. An example is seen in the joint block of granite on the flood plain previously described (fig. 1, *P*, and pl. 4, fig. 1), dragged here in 1902, which has weathered to such an extent in the intervening time that the edges are rounded and the whole surface is pitted with spaces once occupied with feldspar crystals. A narrow quartz vein, now standing out conspicuously on account of its slight solubility, exhibits the process of *differential weathering*.

The many granite outcrops in the Park, exhibit other important phases of weathering of the hard rocks into soils. Along Tilden Street leading down to Pierce's Mill (pl. 5, fig. 2) is an old quarry exposure which lends itself to photography better than those in the Zoo. Here within a few feet the change from the solid granite with jointed structure into the decayed subsoil above still retaining the outlines of the *joint planes*, and, finally, the soil with present-day plant growth, is quite evident. In this process of weathering by solution, boulders are sometimes formed which, when carried away by streams, may be deposited with boulders of other origin to form the sedimentary rock, *conglomerate*. The formation of such *residual boulders* (pl. 5, fig. 1) occurs when water percolating, for example, along the joint planes of the granite, slowly disintegrates by solution the outer parts of the blocks into decayed material, leaving the central part the last to be attacked. This then, unless the waters have had time to permeate to the very center and cause the decay of the entire block, remains as a hard rounded mass to be washed out as a boulder at some later time. This process results in spherical boulders, whence the name *spheroidal weathering*. Since water is a necessity in the process, such weathering is an indication of a moist climate. In dryer climates or where there is considerable alternation of heat and cold, as in the very hot days and cold nights of desert regions, *exfoliation*, a special type of weathering, occurs. Here the outer layers of such a boulder expand under the action of heat but upon

contracting with the cold of night fail to occupy the same space as before and tend to exfoliate or split off in thin sheets. Boulders of this type rarely occur under the moist conditions of the park.

In the northern part of the Zoo occur narrow bands of a darker colored crystalline rock which may be recognized at the surface by the slippery soil into which it weathers. This is *diorite*, an igneous rock composed of more basic minerals (feldspar and hornblende) intruded into the surrounding rocks and weathering at the surface into *soapstone*. This *basic rock* with its weathered soil is quite in contrast with the light-colored acid granite so prevalent throughout the park. A still more basic type, *gabbro*, is one of the igneous intrusive rocks elsewhere in the park. One band of diorite continues to the northeast, where outcrops in the vicinity of Albemarle Street and Connecticut Avenue outside of the park supplied the impure soapstone blocks which the Indians in former days carved into pots and kettles. Traces of the old *Indian quarries* are still extant, and it is not improbable that the park itself contained such quarries. The boulder beds overlying the ancient granites and other rocks of the park have also been the site of Indian quarries, notably along Piney Branch near Sixteenth Street, where incomplete hatchets and arrowheads (*artifacts*) are found, particularly in the streams draining from this region.

ADAMS MILL ROAD GEOLOGY

Coming back to the bear pits and following the path to the Adams Mill Road entrance at the top of the hill, one first notes several faults and *folds* in the schists (fig. 1, *C*) as indicated by their various angles of tilting. Another feature is the evidence of recent erosion by human agency in the worn stone steps cut in the original rock. The pillars at the Adams Mill Road gates again give opportunity for the study of rock classification (pl. 6) and the effect of the weather upon them just as at the Harvard Street entrance. As we leave the park, good exposures a short distance to the right along Adams Mill Road (fig. 1, *O*) show the normal occurrence of the Potomac formation pebble beds over the pre-Cambrian schist, but a few feet to the left of the gates (fig. 1, *F*) this succession is seen to be reversed by faulting. This particular *fault* although of small magnitude is of such interest that a protection against the weather and the small boy has been built around it. Here, along an oblique fracture in the earth's crust, pressure from the southeast has thrust the rocks on one side forward over the other, producing a *thrust fault*. After present-day weathering and removal of the upper part of the rocks, the normally underlying schists are now seen to overlie the Lower Cretaceous sands and gravels. The movement along this fault line is plainly registered on the boulders and schists at the point of contact by scratched sur-

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faces, called *slickensides*. It is also indicated by the finely powdered crushed rock (*gouge*) now represented by clay. This faulted structure is sketched on the label just within the protecting screen (pl. 7), where the *fault plane* is shown cutting across several of the layers producing a fault zone along which water could percolate freely and minerals might be deposited. Other features related to faults may be studied here, such as the *dip*, the angle between the fault surface and the horizontal plane, the *hanging wall*, the side that overhangs in an inclined fault, the *footwall*, the other side, the *heave*, the horizontal displacement of the rocks, and the *throw*, the vertical displacement.

Proceeding down Adams Mill Road (pl. 8) a rock cut along the east side near its junction with Harvard Street (fig. 1, *A*) shows a considerable thickness of metamorphic rock, folded schists, on each side of a mass of the igneous rock, *granite*, capped at the near end by horizontal sandy sedimentary layers. These outcrops, the surface extension of the bear pit exposures in the park below, embrace all three classes of rocks, besides exposing an instructive geologic *structure section*. The granite is an *instrusive rock*, since it shows it had been thrust from below into the schist, and is also a *crystalline rock*, composed of the constituent *primary minerals*, quartz and feldspar, and accessory minerals, mica and sometimes black *hornblende*, in crystal form. As now exposed the fair-sized granite joint blocks indicate their intrusion into the metamorphic schists by the bending of the latter into an anticline. A *master joint* block made up of many small blocks may be noted in this general area as well as cases of the metamorphosed granite changed into *granite gneiss*. Whether these schists are of igneous or sedimentary origin is still a debated question, but the fact that some of the layers contain small quartz pebbles, apparently of stream origin, seems to indicate that at least certain parts of the schist were originally mud deposits bearing water-worn pebbles. Considered as sedimentary beds these layers show a definite dip, registered by the angle of entrance in the surface, and *strike*, the direction of surface outcrop of any particular layer. The top of this anticline plainly has been worn away and the general surface of the old rocks is undulating. Prolonged weathering by water *solution* and the absorption of water by *hydration* has reduced most of the originally hard granite and schist to material so soft that the finger can easily penetrate it, although the original form and structure of both the igneous and metamorphic rocks are still evident. Many of the rocks, both hard and soft, are stained brown to red, showing *oxidation* of the small amount of iron in them. The gradation from hard rock at the street level up through the overlying disintegrated *subsoil* to *soil* at the top of the outcrop called *residual soil* because formed in place, is also evident. These together

form the *rock mantle* as distinguished from the hard underlying rocks. Here this is also an *acid soil* because composed mainly of the acid mineral silica derived from the *acid rock* granite beneath. Veins of hard insoluble quartz cross both types of rock but remain so unchanged upon weathering that they can easily be detached from the enclosing weathered rocks. Associated with such quartz veins in the granite here and elsewhere around Washington are interesting minerals, particularly hornblende, and in a few places small particles of gold. The feldspar portion of the granite, however, often weathers into pure *kaolin*. Now and then quartz crystals (*rock crystals*) line cavities in veins where they have had enough space to form. Although not visible at this particular outcrop, *dikes*, fractures filled with crystalline material from intruded igneous rocks, are visible elsewhere in the park. At the near end of this outcrop may be seen a depression in the schists filled with boulders, and the sand beds of the Lower Cretaceous Potomac formation. These probably fill an ancient stream valley, but at any rate the outcrop shows the same unconformity between the pre-Cambrian and Mesozoic noted on Harvard Street (pl. 8). *Concretions*, rounded boulderlike objects formed of concentric layers of clay or other material segregated around a central nucleus, are occasionally found in these sandy layers.

Transverse movements within the earth's crust are also recorded in this section, as the schists on the south side of the intrusion show a distinct break along a *fault line* parallel to the street. This can be demonstrated visually by the dislocation suffered by a quartz vein exposed in the bank (pl. 8). Harvard Street is now at hand, and this excursion ends close to the starting place, the unconformity on the terraced slope.

In conclusion, it will be noted that in this short field trip the following items of physical geology are illustrated: Weathering, the run-off or surface water, ground water, the work of the wind, igneous rocks, sedimentary rocks, diastrophism, metamorphism, mountain structure and land forms, comprising, with the exception of glaciation, work of the sea, earthquakes, and vulcanism, the major subjects of this science. For historical geology, rocks and deposits of the pre-Cambrian eras as recorded in the several granites, gneisses, and schists, various formations of the Paleozoic studied by means of pebbles from the Appalachians, boulder deposits of the Mesozoic Potomac formation, the sands and gravels of the Cenozoic and, lastly, the modern flood plain alluvial sediments, and the Indian quarries, comprise the available record.

So many geologic items are visible in this small part of the National Zoological Park, that the following alphabetized index of those italicized in this article seems an appropriate conclusion.

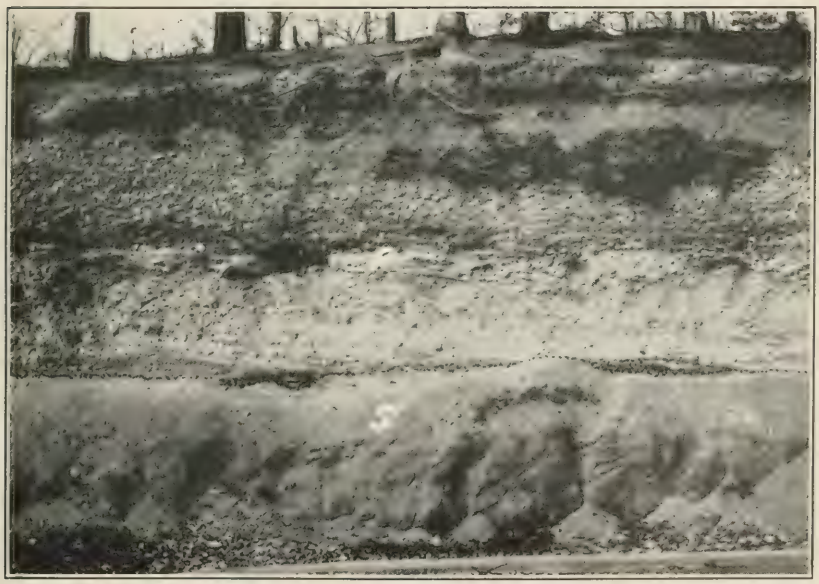
ALPHABETICAL LIST OF GEOLOGICAL ITEMS NOTED IN THE NATIONAL ZOOLOGICAL PARK

Abrasion.
Accessory minerals.
Acid rocks.
Acid soil.
Action of life on rocks.
Alluvial plain.
Alluvium.
Amethyst.
Angle of rest.
Angular unconformity.
Anticline.
Aquifers.
Artifacts.
Atlantic Coast Plain.
Auriferous quartz veins.
Badlands.
Basal conglomerate.
Base level.
Basic rocks.
Biotite mica.
Boulders.
Casts.
Chalcedony.
Chemical decomposition.
Chert.
Citrine.
Clastics.
Clay.
Coal.
Coastal plain.
Cobbles.
Concretions.
Conglomerate.
Contact metamorphism.
Continental deposits.
Corrasion.
Correlation of strata.
Corrosion.
Creep of soil.
Crystalline rocks.
Delta.
Deposition in lakes.
Diastrophism.
Diatoms.
Differential weathering.
Dikes.
Dinosaur gravels.
Diorite.
Dip.
Eolian sandstone.
Erosion.
Essential minerals.
Even sky line.
Exfoliation.
Fall line.
Falls and rapids.
Fault.
Fault line.
Fault plane.
Fauna.
Feldspar.
Flint.
Flood plain.
Flora.
Fold.
Footwall.
Fossils.
Fresh-water deposits.
Frost action.
Gabbro.
Garnets.
Geologic formation.
Geologic section.
Gneiss.
Gold.
Gouge.
Granite.
Granite gneiss.
Gravel.
Ground water.
Guide fossils.
Hanging wall.
Heave.
Historical geology.
Hornblende.
Hydration.
Igneous intrusion.
Igneous rocks.
Indian quarries.
Intrusive rock.
Jasper.
Joint blocks.
Joint plane.
Kaolin.
Levees.
Limonite.
Loess.
Magma.
Marine deposits.
Marine sandstone.
Master joints.
Mechanical disintegration.
Metamorphic rocks.
Meteoric water.
Mica schist.
Milky quartz.
Molds.
Muscovite mica.
Outcrops.
Oxidation.
Peat.
Pebbles.
Pegmatite dike.
Peneplane.
Petrifaction.
Petrified trees.
Physical geology.
Physiographic provinces.
Piedmont Plateau.
Placer mining.
Plains.
Potholes.
Primary minerals.
Pyrite.
Quartzite.
Residual boulders.
Residual soil.
Ripple marks.
Rock crystal.
Rock glacier.
Rock mantle.
Rose quartz.
Run-off.
Saccharoidal sandstone.
Sand.
Sand bars.
Sandstone.
Schistosity.
Schists.
Sedimentary rocks.
Sediments.
Shales.
Siderite.
Silt.
Slickensides.
Smoky quartz.
Soapstone.
Soils.
Solution.
Spheroidal weathering.

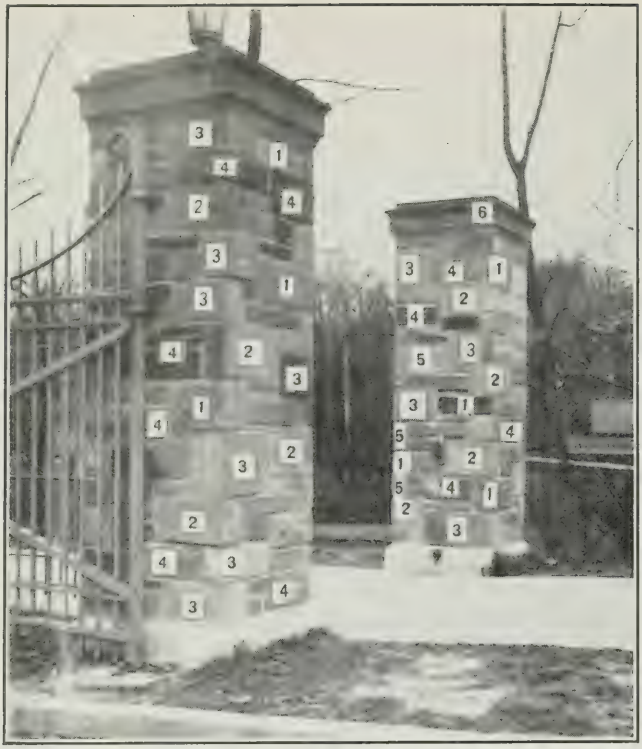
Springs.
Strata.
Stratification.
Stream erosion.
Stream valley.
Strike.
Structure section.
Subsoil.
Sun cracks.
Syncline.
Talus slope.
Temperature changes.
Terraces.
Throw.
Thrust fault.
Transported soil.
Unconformity.
Vein quartz.
Veins.
Weathering.
Wind action.



1. TERRACED SLOPE ON NORTH SIDE OF HARVARD STREET, WITH STUDENT GROUP STUDYING OUTCROP OF UNCONFORMITY BETWEEN PRE-CAMBRIAN SCHISTS (S) AND SEDIMENTARY POTOMAC FORMATION (P).



2. VIEW OF ABOVE BEFORE TERRACING, EXHIBITING THE UNEVEN ERODED SURFACE OF THE OLD SCHISTS (S), THE SAND AND BOULDER BEDS OF THE CRETACEOUS POTOMAC FORMATION (P), AND THE IRON ORE, LIMONITE, DEPOSITS AT THE BASE OF THE SAME IN DEPRESSIONS ON THE SCHIST.



1. THE PILLARS TO THE RIGHT OF THE HARVARD STREET ENTRANCE TO THE ZOO, WITH BUILDING BLOCKS NUMBERED AS EXPLAINED IN TEXT.



2. LEFT SIDE, HARVARD STREET ZOO ENTRANCE, WITH GROUP OF UNIVERSITY STUDENTS.



1. HARD ROCK OUTCROPS AT OLD BEAR PITS IN ZOO NEAR HARVARD STREET GATE, SHOWING GRANITE INTRUSION WITH METAMORPHIC SCHISTS ON EITHER SIDE.



2. ALLUVIAL PLAIN ALONG EAST SIDE OF ROCK CREEK WITH SCHIST CLIFFS CAPPED BY PIEDMONT PLATEAU.



1 A WEATHERED GRANITE JOINT BLOCK WITH THIN QUARTZ VEIN IN RELIEF.
This weathering occurred within the last quarter century.



2. TYPICAL ROCK CREEK VIEW, SHOWING EROSION (CORRASION) BY ANGULAR BOULDERS.



1. OUTCROP OF JOINTED GRANITE BLOCKS EXHIBITING FORMATION OF BOULDERS (B) BY SPHEROIDAL WEATHERING AND THE ACCUMULATION OF A TALUS SLOPE (T).



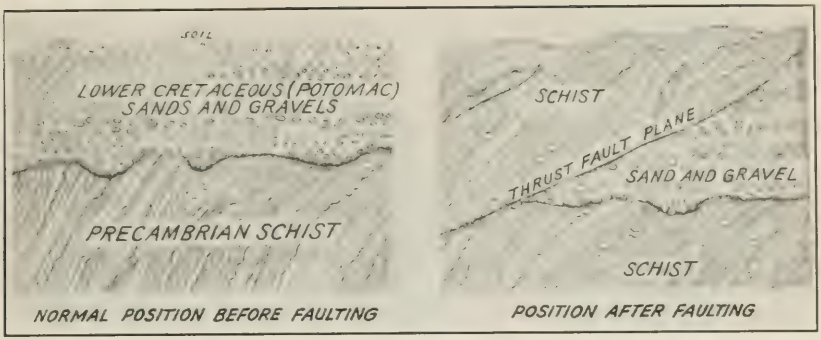
2. OLD QUARRY ALONG TILDEN STREET (NEAR CONNECTICUT AVENUE). ILLUSTRATING WEATHERING OF THE HARD JOINTED GRANITE (G) INTO SUBSOIL (SS) AND THEN SOIL (S).



1. A PILLAR AT ADAMS MILL ROAD ENTRANCE TO ZOO. WITH STONES NUMBERED AS IN PL. 2, FIG. 1.



2. STONE PILLARS ON RIGHT SIDE OF ADAMS MILL ROAD ENTRANCE TO ZOO, WITH DONALD F. MCHENRY OF NATIONAL PARK SERVICE.



1. COPY OF THE EXHIBITION LABEL EXPLAINING STRUCTURE OF THE AREA ALONG ADAMS MILL ROAD NEAR ZOO GATE, BEFORE AND AFTER FAULTING.



2. SHELTER CONTAINING OVERTHRUST FAULT EXHIBIT ALONG ADAMS MILL ROAD NEAR ZOO GATE. FAULT INDICATED BY DOTTED LINE.



1. Near View of Schist Outcrop Along Each Side of Adams Mill Road at Harvard Street, With Quartz Vein (V) Dislocated by a Transverse Fault (F).



2. Outcrop Along East Side of Adams Mill Road at Harvard Street, With Weathered Surface Outcrop of the Igneous Intrusion (G) and Surrounding Schists (S), and the Dinosaur Sands (D) Filling an Ancient Channel.

THE STRUCTURE OF THE EARTH AS REVEALED BY SEISMOLOGY[1]

By Ernest A. Hodgson

Department of Mines and Resources, Ottawa, Canada

[With 3 plates]

You remember what Doc said of Dopey,[2] "He don't know if he can talk or not; he ain't never tried." For the same reason I do not know whether I can succeed or not—having never tried to deal with this phase of seismology before a general audience—but I hope it will be possible for me, without recourse to technical details, to present a clear and convincing picture of the means by which we have learned something of "The Structure of the Earth as Revealed by Seismology."

As usual, "The Greeks had a word for it." Their word for earthquake was seismos; hence, seismology, the study of earthquakes. There is no reason, however, why seismology should be "all Greek" to the layman.

Why study earthquakes? Coming closer home, let us ask the very pertinent, perhaps sometimes disconcerting, question, "Why study earthquakes in Canada?" Throughout this presentation as opportune moments present themselves we shall note phases of the answer—in a series of brief asides.

Earthquakes merit study. According to good authority approximately 800 earthquakes, strong enough to destroy cities and towns, have occurred on land since the beginning of the Christian era. History shows that an average of 30,000 persons have been killed each year during the past 2 centuries by these phenomena. More than 20,000 earthquakes occur each year; a widely recorded shock each 14 hours; a destructive earthquake each 6½ days—on the average, of course.

Perhaps, then, it may be assumed without argument that major earthquakes should be studied. Why be prepared to study them in Canada? Since Cartier's first voyage in 1534, an earthquake of major proportions has occurred in Canada every 50 or 60 years—on

[1] Reprinted by permission from the Journal of the Royal Astronomical Society of Canada, vol. 32, No. 6, July–August 1938.

[2] Walt Disney's Snow White and the Seven Dwarfs.

an average. These earthquakes have been, in general, more severe than the one which, in 1933, caused 50 million dollars damage at Long Beach, Calif. It has just so happened that structures liable to damage were not situated near the origins or epicenters of these shocks. Canada is building up rapidly; the earthquakes will continue. You may draw the obvious and inevitable conclusion.

It was an attempt to ameliorate in some measure the damage caused by earthquakes which led initially to their being studied by scientifically trained men. Progress was slow at first, but there has gradually evolved a branch of the subject which may be called "engineering seismology." Considerable progress has been made of late years, particularly in Japan, in Italy, and in California. It is now possible to design houses which, except in the most extreme cases, will not be destroyed by an earthquake, will not be set on fire thereby, and will not kill their inmates or passers-by with falling debris. Moreover, the specifications for such structures are now written into some building codes, for example those in parts of California.

But, as someone once remarked that Kipling said—"That is another story." It is well to remember that this presentation is limited to a very sketchy résumé of but one phase of seismology. Much will be left unsaid. These "other stories" are not unimportant but at this time we must pass them over. They form part of the answer to the question, "Why study earthquakes?" but not part of the subject, "The Structure of the Earth as Revealed by Seismology."

Taking for granted part of that which we shall later find to have been revealed by seismology, we may consider the earth to be a sphere consisting of three main divisions: A central core, with a radius of about 2,200 miles; surrounded by the mantle, a concentric sphere a little less than 1,800 miles thick; which is, in turn, surrounded by a crust of a varying thickness which may be set down roughly as 25 miles. We take in our stride the responsibility for the approximations as to the sphericity of the earth and the various dimensions given. We shall discuss the theory and the technique of determining earth structure under four different conditions and in the order named: the crust, the mantle, the core, and, finally, returning again to the upper part of the crust—that region which is within reach of the drill.

One of the first things that men learned about the crust of the earth is that it does not have uniform stability. Frequent earthquakes occur only in certain seismic zones. One of the routine activities of seismological investigation is that of locating as accurately as possible all recorded earthquakes. To do this, international cooperation is necessary. At the present time more than 250 seismic stations

are in operation, reporting regularly to each other and to a central station at Oxford, England, where an agency under the joint auspices of that university and of the International Union of Geodesy and Geophysics determines the position of all locatable shocks and publishes a statistical summary of the data. We now know that the most active seismic regions of the world may be defined as a belt about the Pacific with an offshoot zone across Asia and Europe north of India and along the north shore of the Mediterranean to meet another belt running north and south through the relatively shoal water of the mid-Atlantic. We know, further, that all earthquakes are not confined to these more active belts. We have very good reason for saying that there is no region of the earth in which a major earthquake might not take place. This international service was begun in 1895 and has been growing steadily ever since. Canada has participated since 1897.

How then can seismic stations determine from their records where an earthquake has occurred? It would take much too long to sketch the slow degrees by which men learned to construct seismographs and deduce the method of interpreting from their records the distance from the recording station to the source of an earthquake. The abstract mathematical foundations of the theory were laid as early as 1849, but it was not until 1889 that, by chance, the first record of an earthquake was made at a distance. At that time an earthquake in Japan was found to have been recorded on a very sensitive instrument at Potsdam, Germany, set up for the purpose of determining to what extent the land itself has tides similar to, though smaller than, those caused on the sea. Not until 1900, however, was such a distant earthquake record interpreted to yield a value of the distance from station to origin.

Before explaining how distance can be read from the record, we must know just a little about the instrument known as a seismograph. Suppose someone asked you to describe a lady's hat—not some particular hat—just a hat. That difficulty is comparable with an attempt to describe the appearance of a typical seismograph. Such instruments vary in size from one you could hold in your hand to one which stands more than 6 feet high and weighs 20 tons. One thing, however, seismographs have in common. A relatively heavy weight is held very delicately suspended from a framework which is, itself, in firm contact with the earth. When the earth moves, the weight stays behind as you tend to do when the streetcar starts suddenly. The relative motion of the weight and the frame attached to the earth is recorded continuously and gives the record. When the earth is at rest the record line is straight. When a shock impulse arrives, the line is deflected. At regularly timed intervals, usually once a minute, a slight motion is given the recording mechanism so that a small,

recognizable offset (or in some cases, a short interruption) occurs on the line. A diagram of one sort of seismograph is shown in figure 1 together with a small section of a record showing the timing marks. All we wish to emphasize here is that an instrument has been developed which enables the inertia of a weight to give us a record indicating that an impulse has arrived at the recording station and telling us the exact moment of its arrival.

The earth is an elastic body—almost as elastic as steel. That is to say, if any part of it be deformed slightly by force, that deformation will vanish when the force is removed. It is the elastic properties

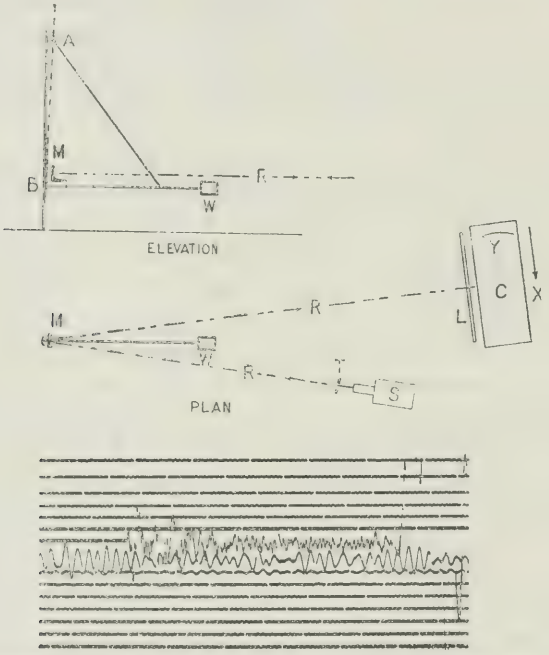


FIGURE 1.—Schematic diagram of a typical horizontal seismograph and a section of a record showing time breaks and an earthquake.

of steel, for example, which cause a suspended bar of the material to give off a ringing note when struck by a hammer. It is the elastic properties of the earth which cause it to transmit earthquake waves.

As early as 1849 it was deduced mathematically that an elastic body should transmit two kinds of waves, and mathematical expressions for the speeds of the two waves were found. These two classes of waves are known as longitudinal and transverse. The first is propagated by the back-and-forth motion of the earth particles in the direction of the wave, somewhat after the manner in which a bump from an engine is transmitted down a long line of freight cars. The

second is propagated by a transverse motion of adjacent particles somewhat after the manner in which a water wave travels; the floating debris shows that the water particles move at right angles to the direction of propagation of the wave.

The difference in velocity depends on the elastic properties of the body through which the waves travel. For short distances it is a sort of neck-and-neck race. No laboratory is large enough to enable the waves to separate sufficiently for the fact to be established experimentally. So for many years there was no experimental verification of the two types of waves. After earthquakes were registered at considerable distances, it was found that a second burst of energy showed on the record among the dying vibrations of the first impulse (see fig. 2). The greater the distance from earthquake to station, the greater was found to be the separation of these two impulses. It was finally established that these were the arrivals of the two types of waves which had left the origin of the earthquake together but had

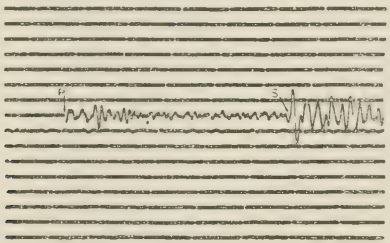


FIGURE 2.—Section of a seismogram showing the *P* and *S* phases.

traveled at different speeds. The difference in time of arrival is thus a measure of the distance.

The two types of waves of which we have been speaking are designated, respectively, *P* and *S* waves by seismologists since, in point of time of arrival, they are primary and secondary. It is readily seen that, if observers possess a timetable showing the time required for the *P* wave to reach various distances on the earth's surface and a similar one for the *S* wave, a table could be prepared showing the relation between *S*—*P* times and the epicentral distances. The first table of this sort was prepared by Oldham in 1900, and since then a steady improvement has been effected. Such compilations are called time-distance tables or, if plotted on graph paper, time-distance graphs. Given the table, it is easily seen how the distances from each station to the epicenter can be deduced. Now, if it be known how far the epicenter lies from any station, then the epicenter must lie on a circle drawn about that station with the proper distance

radius. If the circles for all the stations be drawn, their point of intersection makes the x which marks the spot (see fig. 3).

A well-defined earthquake can be located no matter where it may have occurred. Thus, routine statistical seismology is piling up accurate records of where earthquakes occur and when. Furthermore, we are now able to deduce the depth at which the shocks originate.

The point within the earth from which the earthquake energy is liberated is called the focus; the point vertically above it on the

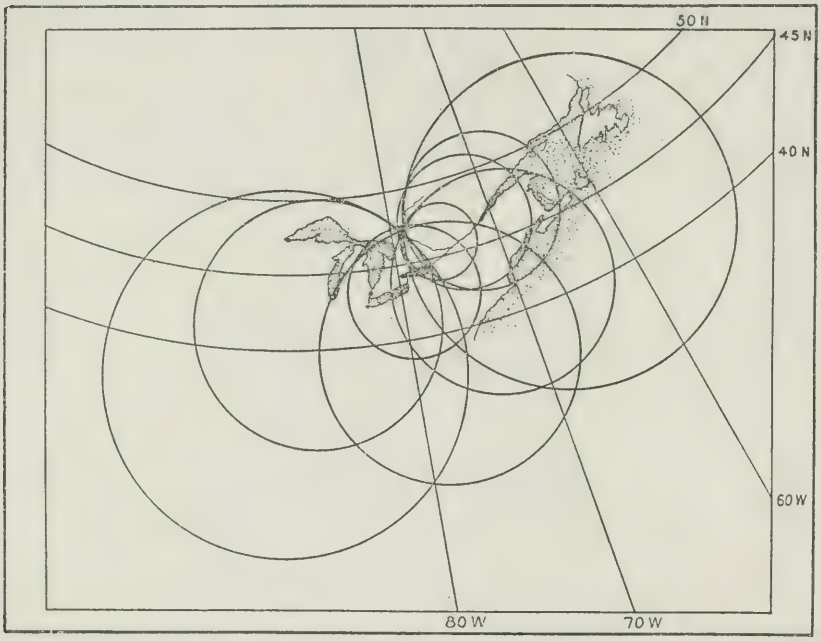


FIGURE 3.—Intersection of distance circles indicating the epicenter of the Timiskaming earthquake of November 1, 1935. (Plotted on stereographic projection.)

earth's surface is called the epicenter. Now if the focus be at or near the surface, we have what may be called, for want of a better name, a normal earthquake. To simplify our discussion we shall from this point confine our attention to the *P* wave—the first impulse on the record. Obviously, the time-distance graph of a normal earthquake begins at the zero-zero point—at the origin of coordinates. Suppose another earthquake should happen with the focus at a depth of, say, 100 miles. All distances for our time-distance graph are measured from the epicenter. The epicenter is thus at zero distance. The time required for the impulse *P* to reach the epicenter at distance zero is in this case more than nothing and the time-distance graph must begin a certain distance up on the time axis, that is, it must

begin above the graph for a normal earthquake. But, at the antipodes of the epicenter, the shock must arrive earlier for a deep focus than for a normal one and the second curve must here lie below the first. The curves must cross. If the focal depth were 200 miles, the new time-distance graph would start even later and arrive earlier than before—and so for successively greater depths of focus. A typical pair of graphs is shown in figure 4. If the arrival times of the *P* wave at a sufficient number of stations can be obtained, it is possible to determine from such a set of curves not only the distance to the epicenter but also the focal depth. In passing, let us note that Canada with her great expanse of territory would leave a wide gap in many of these curves did she not maintain a certain number of

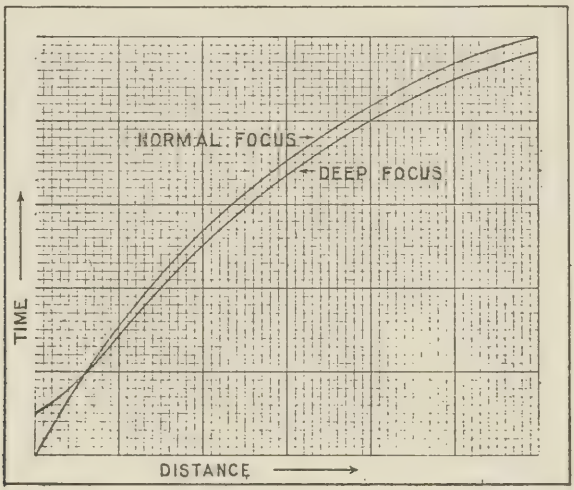


FIGURE 4.—Characteristic form of the time-distance curve for normal focus and for deep focus.

stations at strategically spaced positions. Her seven stations are little enough coverage for a country of such dimensions.

Depths of focus as great as 500 miles and more have been established and are a distinct contribution to the knowledge of the structure of the earth. They show that the earth can sustain built-up strain at depths previously considered impossible. We can no longer maintain that the crust alone is crystalline and that the mantle is plastic. At least the mantle is not plastic in the sense it was thought to be until deep-focus earthquakes were established as a fact. Probably no contribution of the science has aroused a greater interest among those concerned with learning something of the structure of the earth.

But such depths are taking us into the mantle of the earth, and we are not yet finished with our consideration of the problem of

determining the structure of the crust. It is interesting to go back to an early experiment which is in a sense the beginning of our probing of the earth's crust by elastic waves. In 1859 Robert Mallet, an Irish investigator, undertook to measure the velocity of elastic waves caused by blasting in a quarry at Holyhead Island. His methods were crude but carefully carried out, and his distances were short—a little over a mile. He found velocities of from 825 to 1,660 feet per second. In 1878 Henry Abbot, an officer of the United States Army, carried out some experiments to determine the velocity of elastic waves caused by gunfire. His distances were greater than those of Mallet—of the order of 13 miles. His deduced velocities were much greater—up to 5,900 feet per second. Mallet learned of these results and disputed them. We need not go into details regarding the controversy further than to say that, each being prepared to stand beside his respective determination, the conclusion adopted was that the higher velocities of Abbot's experiment were the result of using greater explosions. In other words: the velocity of elastic waves depends on the intensity of the generating force. This conclusion was in error. It was considered doubtful at the time and led to further experiments. After some years sufficient data were obtained to establish the true explanation which we may now examine.

Suppose that the upper stratum of the earth transmits elastic waves at a velocity which is less than that for the deeper-lying material. In this case, deeper means something of the order of 50 to 100 feet. The diagram in figure 5 shows the approximate path of two rays of the waves propagated from an explosion at the surface. Let us take for granted that the rays are of the form shown and concentrate on visualizing the speed with which the nose of the advancing wave radiates over the surface.

If the surface were a calm lake, we could see the water waves radiate in ever widening circles from the shock. Those waves would be gravity waves, not the elastic waves which we are now considering; but the same sort of ever widening circles marks the progress of the energy transmitted by the earth. If the surface were covered with a thin layer of mercury we could actually see the nose of the disturbance spreading out from the source. If we were to put a dish of mercury on the ground at a not too great distance, we could see a segment of the expanding circle pass over it. If we wish to know very exactly when the energy passes regularly spaced points on a line extending outward from the source to a considerable distance, say 20 miles or more, we place sensitive seismographs at those points and have them record on a strip of moving paper on which time marks are simultaneously recorded. In this way we can tell when the initial impulse reaches each station and, if the seismo-

graphs be properly designed, we can also discern the arrival of later impulses—points on the common radius through the source, of the familiar circles-within-circles which can be seen when gravity waves radiate from a stone thrown into still water and are reflected from the shore or other obstacles.

A little consideration is sufficient to show that, near the source, the arrival of the wave at successive stations will be at the rate V_1, if we

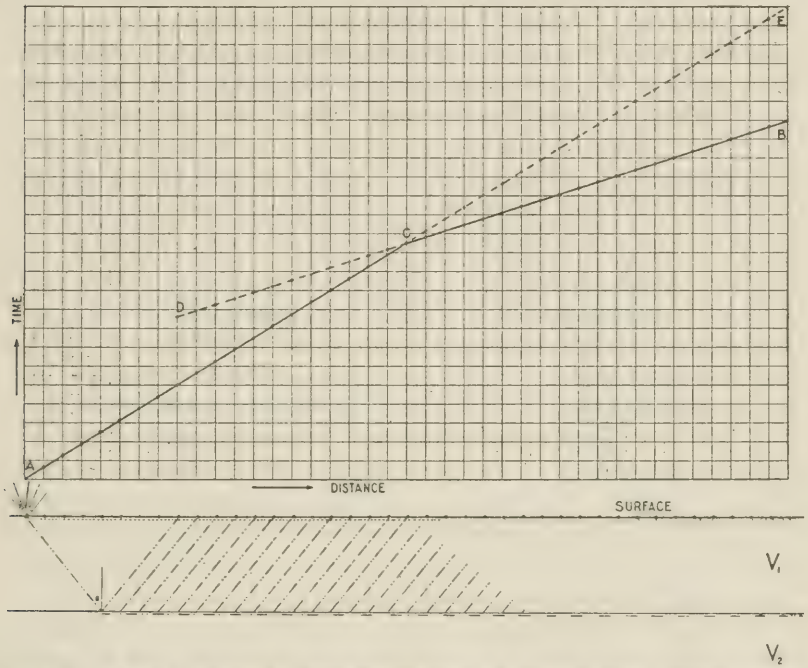


FIGURE 5.—Diagram illustrating the refraction method of probing surface layered structure. Velocities in the upper and lower layers are respectively V_1 and V_2. At distance C the energy by surface and subsurface paths arrives simultaneously. For lesser distances, the earlier arrival is by the surface path. For greater distances, the earlier arrival is by the subsurface path. The critical angle a depends on the velocities V_1 and V_2 which are given by the two graph slopes. Having V_1, V_2, C, and a, the thickness of the upper layer may be computed.

may so designate the velocity in the upper layer. At a particular distance from the source is some station at which the energy, traveling along the surface with velocity V_1, will arrive at the same instant as that which has traveled down to the surface of discontinuity at velocity V_1 along the under surface of that layer at velocity V_2, to a point from which it rose again to the surface with velocity V_1. The greater distance traveled is just compensated for, by part of the path being traversed at greater velocity.

We can readily see that to get from one point to another in New York City for short distances we can travel to better advantage by

surface streetcar, but for greater distances we make up for the time spent in going down to the subway and climbing out at the other end by the higher speed with which the subway carries us. At some point not too far distant it would be an even race to go via the surface or via the subway; beyond that point the subway would be the quicker route.

Let us suppose that we are equipped with properly designed seismographs at each station, from the source outward. The records for the very near stations will show only one arrival—the wave through the surface layer. At a certain minimum distance (which depends on the thickness of the upper stratum and also on the angle with which the ray reaches the surface of discontinuity, the latter depending, in turn, on the ratio of the two velocities V_1 and V_2) energy will begin to arrive via the lower path; but it will arrive after the surface-transmitted energy and will appear on the record as a second impulse. Farther out will be a station at which the energy by the two paths arrives simultaneously. Beyond that point, the first impulse will be that arriving via the lower stratum; but there will still be a second impulse on the records, due to the energy via the upper stratum. The arrival times of the two classes of impulse may be plotted and will result in defining two intersecting straight lines as shown in the diagram. The slope of these lines gives the velocities V_1 and V_2. The point of intersection C defines the distance at which the arrivals by the two paths are simultaneous. The two velocities enable us to define the angle with which the ray impinges on the surface of discontinuity. Knowing the distance to the point of intersection, the two velocities and thence the angle of incidence, we can determine the depth of the upper stratum.

It is now clear why Abbot's velocities were greater than those of Mallet. Abbot was working at greater distances (8 to 13 miles) and was measuring the velocities, at depth, in a high-speed stratum. Mallet was working at distances of about a mile and was measuring the velocity in the upper, slow-speed stratum.

Considerable time has been devoted to explaining this seismic method of determining the thickness of a surface layer and the velocities in the upper and lower strata because it is so important and far reaching in its application. The method can be extended to more than two layers—three, four, or even more—yielding the thicknesses of the layers and the velocities in each. It can be used to determine also whether the surfaces of discontinuity are parallel to the surface or tilted and it will give the angles of tilt. It is known as the refraction method and will, henceforward, be referred to by that name.

In attempting to explore the entire thickness of the crust (about 25 miles) a difficulty presents itself—the explosions we can safely and economically use are inadequate to produce energy sufficient to travel

to the depths and distances required. Recourse must be had to earthquakes—not severe, but well located. Such small shocks usually follow a severe earthquake and are known as aftershocks. Immediately after a major earthquake, portable seismographs may be rushed to the epicentral region, a timing system arranged, and continuous records made. The aftershocks will originate not far from the original source. Several hundred, sharply defined, will often be experienced. The data obtained yield much information as to the structure and thickness of the earth's crust in that particular vicinity.

Studies of this kind have been made in Japan, in central Europe, and in California. The crustal structure determined for Japan seems to be the simplest, that in California the most complex. No such studies have been made in Canada, but the data obtained from the records of the Timiskaming earthquake of 1935 show that the velocity in the outer edge of the mantle immediately under the crust is higher in Canada than in the outer edge of the mantle under Japan, central Europe, or California. However, we are here considering the methods of determining earth structure, not the results obtained, so we shall pass on to the methods of probing the mantle of the earth: that spherical shell about 1,800 miles thick below the crust and above the central core.

Before doing so it is necessary to note one further very necessary contribution from crustal analysis. In speaking of the methods used for locating earthquakes care was taken to say, "given a dependable time-distance graph." Science gives nothing gratis and yields her most valued and most valuable data only to those who seek; though sometimes, it is true, they do not know exactly for what they are looking or why they require it. One of the difficulties of obtaining a time-distance graph has been mentioned—the great areas on both land and sea unserved by seismograph stations at which to record the exact time of arrival of the elastic waves from an earthquake for which is accurately known the epicenter, focal depth, and time of occurrence. Even had we the optimum distribution of stations, it would still be necessary to have, for each of a series of selected earthquakes, the position of the epicenter, the focal depth, and the focal time. In other words, to locate an earthquake we must have accurate time-distance graphs, and to construct such graphs we must accurately locate an earthquake or earthquakes. It appears to be an impasse; but seismology has advanced, nevertheless, by a series of approximations—applications of the method of "cut and try."

Progress has been slow but steady over the years, as seismologists have gradually arranged for more stations, devised more efficient seismographs, and perfected timing arrangements. We may not

here enter into details. Suffice it to say that remarkably good time-distance graphs are now available—so good that it is becoming necessary to take account even of the fact that the earth is not quite spherical.

The location of epicentral position and the determination of focal depth and focal time (for earthquakes which can serve to improve the existing time-distance graphs, yielding more accurate values for focal depth which we have seen to be of so much interest) are to be accomplished only by means of seismographs concentrated over an actively seismic area. The instruments must be in place at stations situated near a prospective earthquake source and must operate continuously until a shock occurs sufficiently strong to be recorded up to great distances. The near-station data can then be used, after the manner of the refraction method previously described, yielding definite knowledge of the epicentral position, focal depth, and focal time. These, with accurately timed registration at stations over the entire distance range (or as much of it as possible), will permit a new refinement of existing time-distance graphs.

A sufficient concentration of seismographs over a seismic area is found at only a few places in the world—at the present time in Japan, central Europe, and California. Now, for an earthquake at any one of these places, some parts of the distance range must lie over water-covered areas where seismographs cannot be placed and also over other regions where, as yet, no stations are in operation. It is for this reason that efforts are being made by all seismologists to continue the operation of existing stations at as high an efficiency as possible and also to arrange for the inauguration of new stations at strategic points. Canadian stations are particularly valuable, as yielding data for important parts of the distance range otherwise not covered, for earthquakes in Japan and California.

In order to cooperate in the attack on this major problem of seismology—the perfecting of the basic time-distance tables—a seismologist may decide to make a complete study of all records of some earthquake which appears from preliminary reports to be a promising source of fresh data. Requests are sent out to all the seismograph stations of the world asking for the loan of their records for this particular earthquake. Such a thorough study may extend over as much as 2 years. Canada has made complete studies of three major earthquakes and has loaned records of many others to seismologists engaged in research. Studies of this kind are most efficient means of obtaining data for furthering our knowledge of earth structure.

Let us, then, take for granted that we have a perfected time-distance graph for the P waves of a normal earthquake. That is taking a great deal for granted, but we already have very good graphs and

we fully expect to have better ones as time goes on. The hypothetical, perfect graph tells us the rate at which the nose of the ever widening circle of *P* waves is radiating outward from the epicenter about the surface of the earth. That is all we ask to know. It is this we crave to apprehend better year by year.

If we knew the varying velocity with which this surface circle of energy progresses throughout the entire distance range from the epicenter to its antipodes, we should be able to deduce the rate at which the waves travel at various depths within the earth and through what surfaces of discontinuity they pass. We may speak of the nose of surface energy as the trace of the waves and speak of its velocity as the trace velocity or apparent surface velocity in contradistinction to the true wave velocity at any point within the earth.

The time-distance graph gives the data for determining at any given distance the trace velocity; for we have only to find the rate at which distance varies with time at that particular distance range. For example we can take as our distance say 2,500 miles. We find how long it takes the trace to reach a distance of 2,500 miles by simply reading the ordinate of the graph for this distance. Now we read off the time it takes to go to 2,600 miles. The difference in these gives the time it takes the trace to travel 100 miles at the distance 2,500 miles. For those who are used to the process we simply say that the tangent to the time-distance curve at any distance value gives the apparent surface velocity or trace velocity at that distance. Suffice it to note that it may be deduced from the time-distance graph.

The most difficult part of the task set by this discussion now appears: that which the speaker so far "ain't never tried yet." It is hoped, however, that it may prove feasible to present, without recourse to technical details, a clear and convincing picture of just how the time-distance graph contains in its very shape the data from which may be deduced the velocity at any given depth within the mantle of the earth.

Before doing so, it is necessary to take drastic liberties with the earth. We have a time-distance curve for an earth, the crust of which varies from one point to another. We require for consideration a time-distance curve for an earth stripped of its outer crust. We may not be able to do this physically but we can use our knowledge of surface structure to cut off a little bit of distance and a little bit of time from each end of every focus-to-station path, obtaining time-distance values for that part of the earth which lies below the crust.

If you had a timetable showing the actual time it would take you to go, via subway, from Times Square to the surface levels at various subway stations in New York, you would not have a fair appraisal

of the various rates of travel on the subways concerned; for some subway platforms are deeper than others and some are more difficult of access. If you took off from the tabulated values the distances traveled forward in going down the steps on entry and in ascending on exit you would have new distance values in each case. If you deducted the time spent in entering and leaving you would have new time values in each case. Using these corrections to make adjustments to the original timetables, you would have, in effect, stripped off New York to the subway level. At least you would have developed a subway-level table from a surface-level table.

After a procedure somewhat analogous, we may assume we now have a new and hypothetically perfected time-distance graph for an earth stripped of its crust. We know that by applying the refraction method we can obtain the time velocity just at the bottom of the

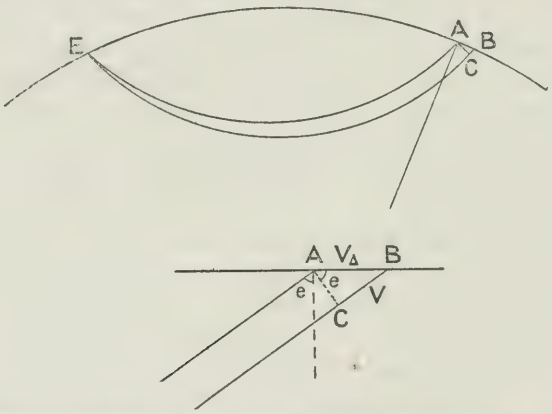


FIGURE 6.—Diagram illustrating the method of deducing the angle of emergence, *e*, of a ray at any chosen epicentral distance, *EA*.

crust and in the outer edge of the mantle. We assume that, throughout any part of a concentric spherical shell defined by any given radial distance from the earth's center, the conditions are the same—the true velocities are uniform over the whole shell. Thus, the velocity deduced just below the shell is taken as uniform over the entire earth.

You will remember that it has been stated that we have recently learned that this is not so. The true velocity at the outer edge of the mantle under Timiskaming is greater than that for the outer edge of the mantle in Japan. Very well! we shall have to continue this process of stripping the earth and adjusting our time-distance curve to a still greater depth until our premised conditions are satisfied. It will be sufficient if it is here made plain: That we can use seismological methods to get a time-distance curve for an earth

stripped of all lack of uniformity throughout any concentric shell; that we can find the trace velocity at any distance from the tangent to such a curve; and that we can determine the true velocity at the very surface of our stripped earth by application of the refraction method described for surface conditions. We have also, in effect, moved the origin from some point within the earth—the focus—to a point exactly in the surface of our stripped earth. Our amended time-distance graph begins at zero-zero—at the origin of coordinates. We may choose any point on the surface of our stripped earth and image an earthquake focus there. Proceeding to some distance about the surface of the stripped earth, we come to a point

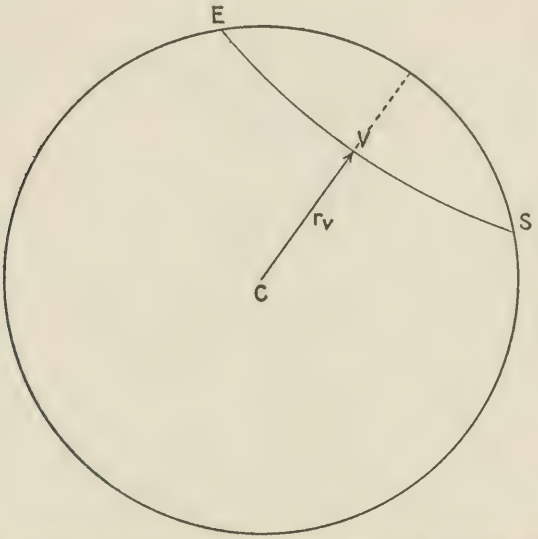


FIGURE 7.—The Herglotz-Wiechert method applied for any chosen epicentral distance *ES* yields the value of the vertex radius r_v and the true velocity of the earthquake waves *V* at that depth.

where the conditions of figure 6 obtain. Here two separate rays from the focus, *E*, emerge at the hypothetical surface of the stripped earth. It is assumed that they are chosen so that the second ray reaches *B* just one second after the first ray reaches *A*. Thus the distance *AB* is a measure of the trace velocity; for it is the distance traveled by the trace in 1 second. We draw the line *AC* perpendicular to *CB;* thus the distance *CB* is a measure of the true velocity at the surface; for it is the distance traveled by the wave along the ray *CB* in 1 second. Now if we know the sides *AB* and *CB* of a right-angled triangle we can measure the angle of emergence, *e*, which is equal to angle *CAB*. We know the trace velocity from the amended graph and the true velocity from the refraction method so we can in

this way find the angle of emergence of the rays at all distances, provided they do not dip into the core and become deflected. Up to more than half the distance around the earth from the epicenter chosen, we can deduce the angle of emergence of the rays.

As we saw in the refraction method, a ray passing from a stratum of lower velocity to one of higher velocity is bent toward the surface. If the true velocity increases at successively deeper levels the ray will be bent more and more until it is at right angles to the radius. This is its deepest point. It then traverses the second half of its path, which is the mirror image of the first half; and it emerges

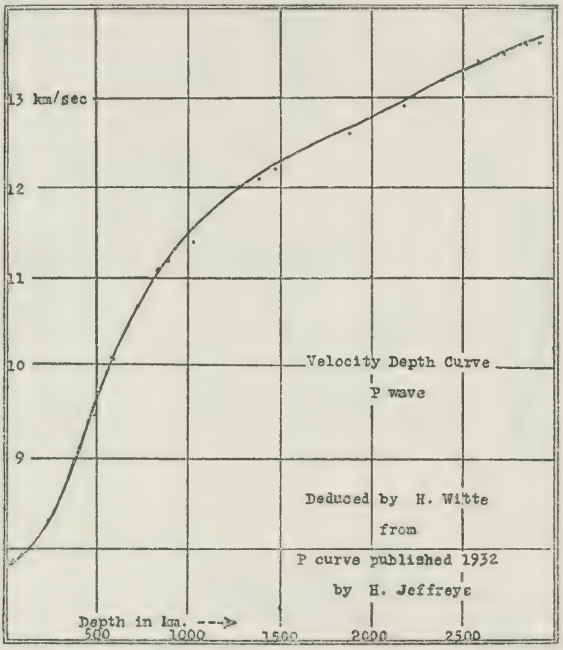


FIGURE 8.—Velocity-depth curve by Witte, 1932, based on Jeffreys' *P* curve.

at the surface (of the stripped earth let us remember) at the same angle of emergence with which it started. That is to say, the ray is symmetrical about its center radius through the vertex. (See fig. 7.)

Clearly the amount of bending to which the ray is subjected is the sum of all the effects within its path; and the angle of emergence of the ray at any given distance is determined by the velocity at every depth through which the ray passed. If we could set up a mathematical expression giving the value of the radius to the vertex r_v and the velocity V at that vertex, of any chosen ray defined by its epicentral distance of emergence, in terms of the emergence angle for that epicentral distance, we could get one value of a true veloc-

ity at a known depth. For, as we have seen, we can determine emergence angles at every epicentral distance on the stripped earth. That, very briefly, is exactly what has been done. It is known as the Herglotz-Wiechert method.

Applying the Herglotz-Wiechert method once for one arbitrarily chosen epicentral distance, we get one vertex depth and the one corresponding true velocity. Applying it repeatedly, we get other

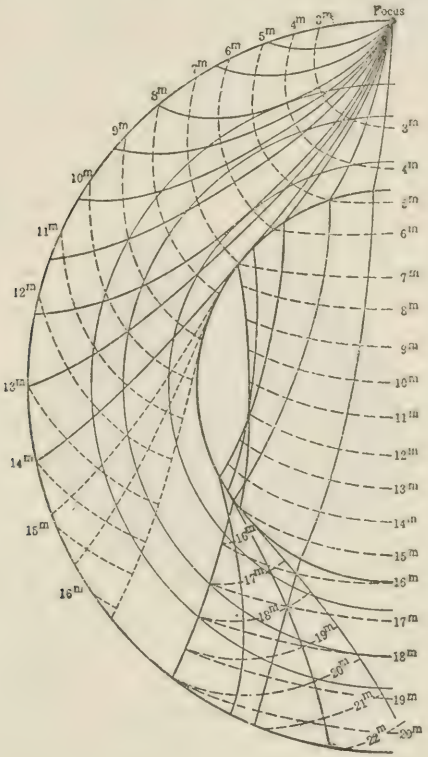


FIGURE 9.—Cross section of the earth showing rays and wave fronts of earthquake waves and the "blind zone." The last direct *P* wave to emerge at the surface is the one grazing the core whose wave front is marked 14m indicating that the transmission time from the focus to this point is 14 minutes.

depths and their corresponding velocities and thus bit by bit we get the complete graph, which shows the variation of velocity with depth at all distances down to the core. The velocity depth curve deduced by Witte in 1932 is reproduced in figure 8.

Down to the core, why no farther? Because the ray which barely grazes the core is the last direct *P* wave to reach the surface. All others are deflected into the core in such a way that, beyond a certain distance range, no direct ray emerges at the surface. There

exists a "blind zone" as shown in figure 9. No single part of the earth structure defined by seismology is quite so certain as the presence of the core. The blind zone is very clearly demarcated. It is possible to read off directly from a velocity-depth curve, such as that of figure 8, the depth to the core. The fact that the blind zone begins abruptly shows the surface of discontinuity to be sharply defined.

If a mathematician be given the dimensions of the earth, the structure of the crust, the variation of velocity in the mantle, and

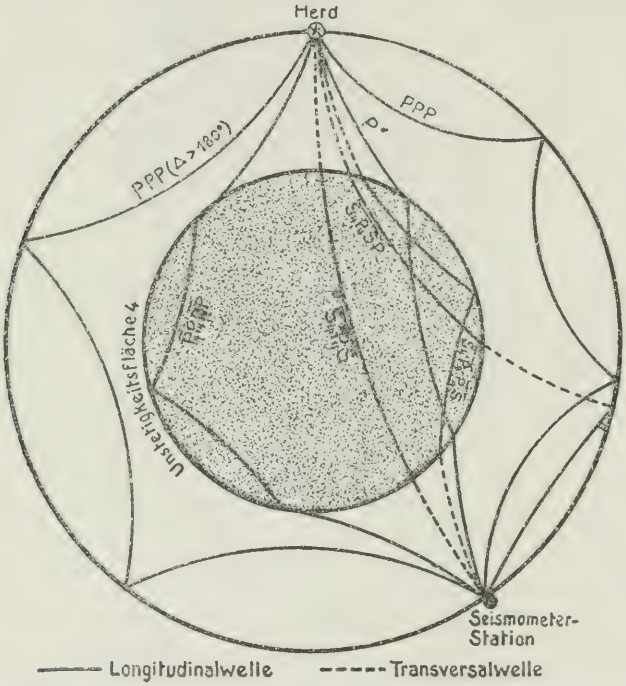


FIGURE 10.—Some typical complex earthquake rays from the focus (Herd). The subscript 4 indicates the passage of the so-called fourth surface of discontinuity within the earth (Unstetigkeitsfläche 4), which marks the boundary of the core.

the depth to the core, he can compute the time it should take various waves, reflected within the earth, to reach the surface, and the seismograms may be searched to see if they confirm the work which gave us the velocity-depth curve—not only the reflected P waves, but the S waves which we have nearly forgotten; for, as we got a velocity-depth curve for the P waves, so we can get one for the S waves. Furthermore, when an elastic wave either of P or S type is reflected or refracted it generates other waves of both types. Thus we may have a P wave reflected at the under side of the surface as

an *S* wave, and so on. The number of such possible complex wave paths is very great, and the times, once computed, may, as we have said, be checked on seismograms. Some of the possible paths are shown in figure 10.

So, step by step, by cut and try, by modification of theory and data, we have the means of probing the earth not only in the crust but in the mantle down to a depth of about 1,800 miles. But we stand at the barrier—the margin of a core of radius 2,200 miles. What can we learn about the core?

We can learn something of the nature of the material in the crust and mantle by knowing the velocity with which earthquake waves traverse them. We know from gravity measurements the total mass

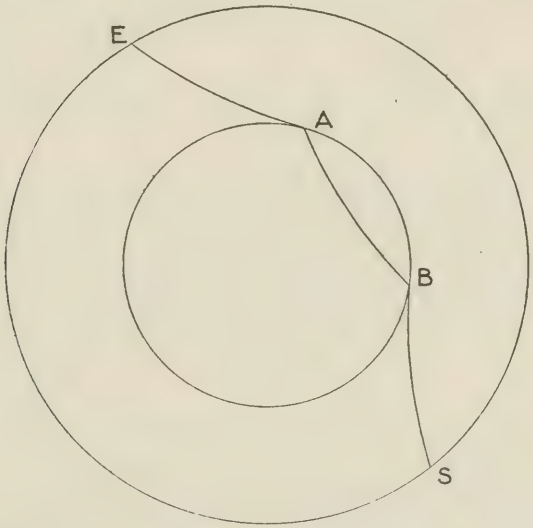


FIGURE 11.—Path of *PKP*-ray, sometimes designated P_4P_4P or P_cP_cP.

of the earth. The mantle and crust do not nearly make up their share of mass per volume (density). The core must be very heavy; the density must be great. We can deduce the approximate average density of the core. If we had a time-distance curve for the core and knew the true velocity just inside its boundary, we could apply the Herglotz-Wiechert method again to an earth stripped to the core and find a velocity-depth curve for those greater depths. So far no means has been found to do this. We know the total time for a wave such as that shown in figure 11 to reach the surface. We can compute the time required for the sections outside the core, and we can find the end points of these branches at the core boundary. We know thus the time required for a wave to traverse the core

along a path which has its end points fixed. But, not knowing the variation of velocity with depth in the core, we cannot say what shape the path has therein.

However, to make a long story short, there are, as we have partly indicated, a certain number of conditions which must be met if an assumed variation of velocity with depth within the core can be true. Over 20 such variations have been assumed by Gutenberg, checked with end data, and the most probable one selected. The research continues. We have still much to learn about the core.

Returning to the surface, let us see how we may use seismographs to probe the outer layers of the crust to depths which the drill may

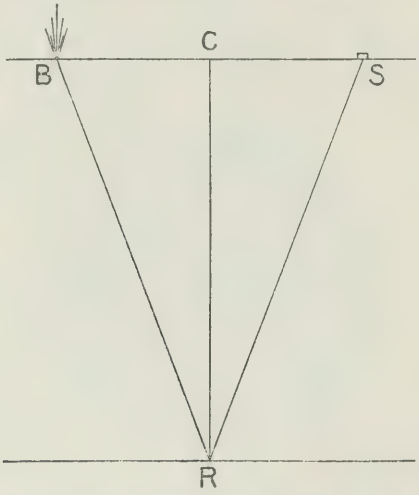


FIGURE 12.—Ray from blast to seismograph. The average velocity from the reflecting layer at *R* to the surface is found from shots fired in dry wells in the region, or by refraction shooting. The elapsed time, shot to seismograph, is known. Hence the distance *BRS* is known. The distance *BS* is measured. Hence the depth *CR* may be calculated.

reach and confirm. We may use the refraction method which was described; and indeed it was used to excellent effect up to about 1929, when researches in radio made possible a new method which is now so useful that, in the United States alone, more than a million dollars a month are being spent in applying it to probe the upper earth strata in search of oil.

It is known as the reflection method. A shock generated from the explosion of from a quarter to a half pound of dynamite is recorded on a series of seismographs placed a measured number of feet apart at a measured distance from the blast. A very common "spread" is to have six seismographs at intervals of 50 feet with 1,000 feet from the nearest seismograph to the shot point. The shot

is buried in a hole, drilled usually 50 feet deep; and the recording is done on very rapidly moving paper with time marks recorded each hundredth of a second. Space fails here to do more than say that this method uses electrical seismographs which feed their impulses through wave filters and amplifiers so that the direct ground motion is killed out and those waves enhanced which have been reflected from a selected subsurface stratum which is thought to have oil-bearing possibilities.

The average velocity within the upper strata above the reflecting layer being studied can be measured by the refraction method or, where dry wells exist in the area, by measuring "up-hole time" from a shot in the well. Knowing the average speed and the elapsed time, and the distance from shot to seismograph, we have sufficient data to solve the conditions shown in figure 12 and learn the depth to the reflecting surface.

The crews work over the networks of country roads, finding the depth from point to point to the selected layer or "horizon" within

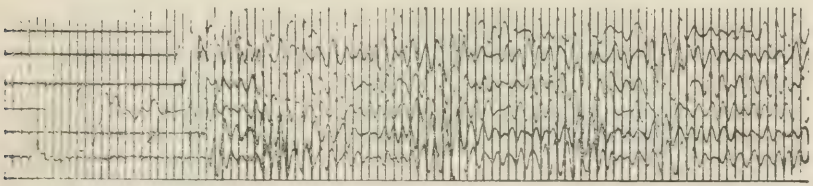


FIGURE 13.—Section of a typical six-instrument seismogram.

the earth, until they find some place where it up-bulges about the same way as a large carpet would up-bulge if you were to put an inverted soup plate in its center. Imagine a carpeted dining room with a table on the center of the carpet and with an inverted plate under the carpet and under the table. The table top represents the earth's surface—the carpet represents the oil-bearing reflecting layer. The geophysicist seeks the invisible, up-bulged part represented by that hump in the carpet pushed up by the inverted plate. In practice, the layer may be at any depth up to a couple of miles. The bulge may be only 50 feet above the general level of the layer. But if such a bulge exists in those invisible depths, to learn of it is worth money; for that is where the oil will be—if there is any.

Plates 1, 2, and 3 show reproductions from photographs taken in the field, and figure 13 shows a typical record. To deal adequately with this subject would take a whole series of lectures, for it is a very live business; and new technique and new discoveries are being reported every month. Some idea of the magnitude of the business may be given when it is stated that more than 200 seismograph crews

are working in the United States alone, and that it costs at least $30,000 to equip a crew and $3,500 a month to run it. Crews with equipment may be hired at an inclusive charge of $9,000 per month. No companies are organized for this work in Canada, but some United States companies and also some from Germany have operated here.

It has been a long story, with many very summary and sketchy flights over details. We have seen how seismology penetrates to depths of a mile or two so quickly and surveys wide areas so rapidly that the expensive wielding of pick or drill need not be resorted to without some reasonable hope of reward. Aftershocks permit the extension of such methods to the bottom of the crust, which we have found to be of varying stability, varying thickness, and varying structure. The work on the crust permits us to arrive at a time-distance curve for a hypothetically stripped earth, after which the Herglotz-Wiechert method enables us to obtain a velocity-depth curve for the mantle. With these data at hand, we may compute the arrival times for various complex waves which should record at the surface, thus checking the previous deductions. We know some things about the core but it still remains to a large extent an unsolved problem—by no means the only one in seismology of course.

So, step by step, year by year, slow but steady progress is being made, by cooperative international effort, toward a more accurate knowledge of earth structure. This is one of the main reasons for studying earthquakes, whether in a seismic region or in relatively quiescent Canada.



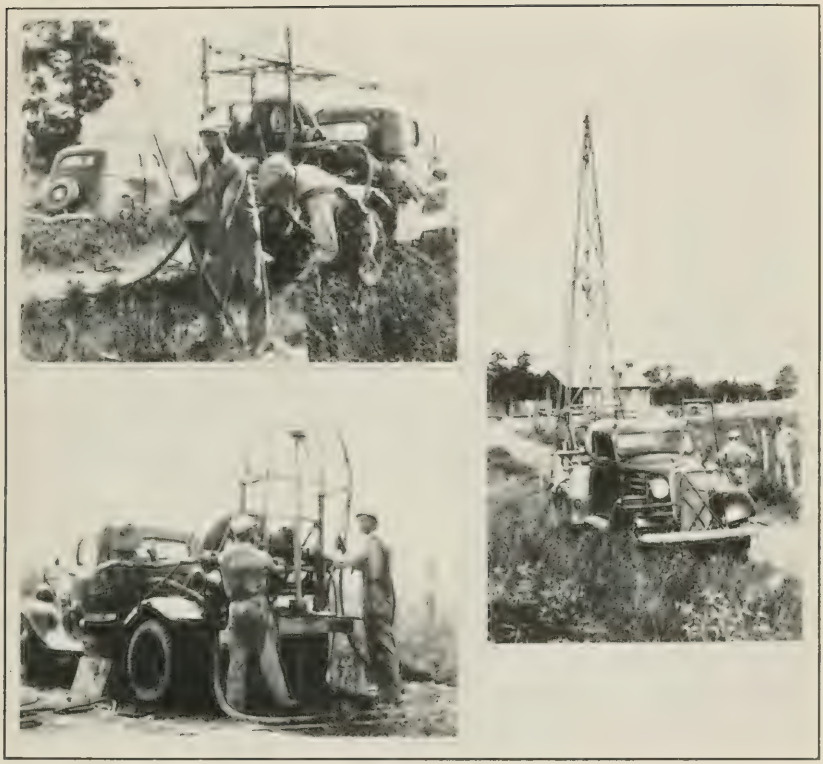
AUTOMOTIVE EQUIPMENT.

Top: The surveying truck.
Middle: The explosives truck and the recording truck
Bottom: Nearer view of recording truck.



SEISMIC SHOOTING.

Top left: Attaching dynamite to loading pole and preparing firing cap and wires.
Top right: Lowering charge with loading poles.
Bottom left: Method of measuring dynamite charges by cutting sections from 2½-pound sticks.
Bottom right: Set up for a regulation shot (in this case bedded with an overload of water).



DRILLING SHOT HOLES.

Left top: Digging sump hole for flushing water.
Left bottom: Applying pressure to rotating drill.
Right: Truck with drilling mast hoisted.

OUR PETROLEUM SUPPLY[1]

By Hugh D. Miser
U. S. Geological Survey

The petroleum supply of the United States is of great importance whether we express the volume and value of the annual output in barrels or dollars, or measure the service of petroleum in terms of human welfare and progress.

Petroleum is produced in many countries, and its products are used in factories, on highways, and in homes in all lands. Although the petroleum industry thus encircles the earth, it is outstandingly an American industry. The drilling of wells for oil in the United States began in 1859. Our country leads in the development of the industry, and it produces and consumes three-fifths of the world's annual output. Also, the United States possesses about half of the world's known reserves of petroleum.

PRESENT PRODUCTION AND USES OF PETROLEUM IN UNITED STATES

Our domestic petroleum production is obtained from about 360,000 wells in 22 States; only a small part—about 5 percent—of our domestic consumption is imported from other countries.

The value of our petroleum output for 1937 measured in dollars is one-fourth the value of the entire annual mineral production of the United States. It exceeds the total value of all the metallic mineral products combined for that year. The next mineral product in point of value is coal, the next is iron, and then follows natural gas.

Chief among the many uses of petroleum is the production of power. Such power drives our 30,000,000 motor vehicles on the land, our Navy on the ocean, and our planes in the air. Altogether, one-third the mechanical energy produced in the United States comes from petroleum and its companion mineral product, natural gas.

Our domestic production through 1937 totals 19,972,000,000 barrels. Texas stands first, having produced 5,127,000,000 barrels, a

[1] Address of the retiring president of the Geological Society of Washington, delivered December 14, 1938. Published by permission of the Director, Geological Survey, United States Department of the Interior. Reprinted by permission from the Journal of the Washington Academy of Sciences, vol. 29, No. 3, pp. 93–109, March 15, 1939.

quarter of all the nation's output of oil. California has produced 4,872,000,000 barrels, 24 percent, and Oklahoma 4,341,000,000 barrels, 21 percent. The output of no other State has equaled the domestic demand of petroleum products for the year 1937—namely, 1,169,000,000 barrels.

Altogether, Texas, California, and Oklahoma have contributed 72 percent of all the oil output of the United States. The total production of each of these States is greater than that of the U. S. S. R.—3,771,000,000 barrels through 1937—which ranks next to the United States in point of cumulative production. Mexico ranks third in total world output, with 1,863,000,000 barrels, and Venezuela fourth, with 1,491,000,000 barrels. No other oil-producing country has produced as much as 1 billion barrels.

The principal petroleum products and their uses form long lists whose presentation time does not now permit. A general grouping of the refined products includes gasoline, kerosene, fuel oils, lubricants, paraffin wax, petroleum coke, asphalt, road oil, petrolatum, absorption oil, and medicinal oil.

Kerosene, the first petroleum product to be utilized in important quantities, is still extensively used for lighting. In addition, it is utilized in increasing volumes to provide power and heat.

The domestic demand for gasoline in 1937 was 519,000,000 barrels, for use chiefly in our motor vehicles. The automobile depends heavily on the petroleum industry; it consumes 89 percent of our gasoline, 40 percent of our lubricants, and requires natural-gas-derived carbon black which lengthens two and one-half to three times the lifetime of our tires. The domestic demand for gasoline is directly related to the number of motor vehicles, which average one to about every five persons. The volume of consumed gasoline, since the introduction of the first American automobile in 1892, parallels the increasing numbers of motor cars. In late years the slight departure from parallelism is due to the greater volume of gasoline used by each car and to the increased use of gasoline in airplanes, tractors, motorboats, and stationary engines. Second only to gasoline were the requirements for fuel oil—442,000,000 barrels in 1937—which is used by railroads, steamships, gas and electric power plants, mines, smelters, manufacturing plants, oil companies, and United States Navy, and for domestic heating. The development of our machine age has depended on a plentiful supply of lubricants made from petroleum. The great volume of demand—23,323,000 barrels in 1937—can be met only by obtaining it from petroleum.

Our petroleum output, as thus briefly described, is provided by one of the Nation's most important industries. The investment in the United States in the five divisions—the producing, natural gasoline,

transportation, refining, and marketing divisions—of the petroleum industry totals about $14,000,000,000.

EARLY DEVELOPMENT AND USES OF PETROLEUM

Before 1859 petroleum and its associated hydrocarbons had been used by the peoples of many lands for at least several thousand years before the Christian era. Seepages and hand-dug pits and shafts provided the entire supply of these materials, except in India and China where oil was obtained from drilled wells. The Chinese, by sinking wells to depths of 1,500 to 2,000 feet for brine, oil, and gas, were recognized as the ancient world's most accomplished well drillers.

The early uses for petroleum and its products were many, as will be noted below.

Asphaltic pitch was used to waterproof the ark of Noah, the cradle of Moses, and the cisterns and silos of ancient Egypt and Mesopotamia. Also, it was used by the Egyptians in the process of mummification. Asphalt was used as a mortar in the construction of Nineveh and Babylon and also in the buried cities of Ur, as early as 4000 B. C. Oil from Sicily was used by the Romans to light the temple of Jupiter, and many centuries later flame throwers fed by naphtha were employed against the Crusaders when they stormed the walls of Constantinople. Petroleum was distilled into products of commerce at Baku as early as the eighteenth century; oil was there used in lamps and also was utilized for cooking in 1723. In Rumania the exploitation of oil by shafts dates as far back as the second half of the sixteenth century. To Rumania is ascribed the first recorded volume of output of crude petroleum. In 1857 that country produced 1,977 barrels, and since then it has an unbroken record of production.

The early American Indians were familiar with natural petroleum seepages. They set their mosaics in asphaltum; they used it as an adhesive substance; they lined their baskets with it; and they had great faith in petroleum for performing all manner of cures.

Oil and gas were known and used before 1859 in many other countries. A search and study of the literature concerning their recovery, transportation, treatment, and utilization before that date reveals a fascinating story of the progress of human civilization.

At the beginning of the nineteenth century, when the supply of whale oil for lighting needs was dwindling, the world was faced with the necessity of finding a reasonably priced substitute for it. This necessity stimulated the research—already being conducted—in the distillation of oil from coal and shale. Paraffin was extracted from both bituminous shale and crude petroleum in France in 1830. Burn-

ing oil in commercial quantity was first produced from shale in France in 1838. The refining of oil at the Riddings Colliery in Derbyshire was begun in 1848 by James Young, and he later obtained oil from coal and bituminous shales. He founded in 1851 the Scotch industry for the extraction of oil and paraffin from boghead coal. His process for obtaining illuminating oil was rewarded with commercial success, and during the next 10 years its use expanded rapidly in Great Britian and was introduced into the United States. American coals were treated in plants in Pennsylvania, West Virginia, Kentucky, and Ohio. This rising industry was soon replaced by the petroleum industry.

During the first half of the nineteenth century increasing quantities of crude petroleum, known as rock oil, were obtained from seepages and from wells drilled for salt brines in Pennsylvania, Ohio, Kentucky, and West Virginia, but very little of it was marketed. Between 1850 and 1855 petroleum from a salt well at Tarentum, Pa., was refined in Pittsburgh and sold for lamp use. Also by 1850 some oil from the locality was bottled and sold by druggists; and about 1855 the oil was refined by methods used for the recovery of oil from coal.

The salt wells in Pennsylvania and the nearby States had been drilled with equipment designed for the purpose. This equipment, which embodied the fundamental features of the modern standard cable drill rig, was developed in 1806–8 in the Kanawha Valley, W. Va. Accordingly, salt well drillers and their equipment were employed for the drilling in 1859 of the Drake well near Titusville, Pa., in which it was hoped that there would be obtained a larger supply of oil than that afforded by the oil springs of the locality. The Drake well, on reaching a depth of 69½ feet, discovered oil and its initial daily output was 25 barrels. This was America's first commercial oil well.

RELATION OF GEOLOGY TO PETROLEUM INDUSTRY

The phenomenal growth of the petroleum industry in the United States has been aided greatly by engineering and science. In the words of W. C. Teagle, formerly President of the Standard Oil Co. of New Jersey, "The operation of the world's oil industry is now very largely in the hands of technical experts, geologists, physicists, chemists, and engineers. This change in the complexion of the responsible operating personnel has occurred more rapidly, perhaps, than in any other field of comparable importance" (18).[2] On the same subject Lord Cadman, head of many British petroleum companies and past

[2] Numbers in parentheses refer to list at end of article.

president of the Institution of Petroleum Technologists, comments, "In no branch of human endeavor has the application of exact knowledge been so apparent as in the exploring, winning, refining, transport, distribution, and utilization of mineral oil. At every point in the long road that leads from the oil well to the consumer investigation and research have been employed with almost spectacular results" (3).

The recognition of the value of the geologists' contribution to the industry finds concrete expression in the fact that most of the companies have geological departments. Oil companies, however, have employed great numbers of geologists only in the last 25 years.

The general acceptance of geology in the search for oil took place about 1915, more than 50 years after the completion of the Drake well. This acceptance was not so much a whole-hearted welcome as it was a necessity, for the oil companies were being pressed to meet the rapidly increasing demands for gasoline required for the growing numbers of motor vehicles.

Although geology was utilized only to a limited extent in the selection of drilling sites during the first half century of the petroleum industry, geologic observations concerning the occurrence of petroleum date back to 1842. In that year William Logan observed the occurrence of oil on anticlines near Gaspé. In 1860 H. D. Rogers noted that the newly discovered fields in Pennsylvania were located on anticlines. In the following year T. Sterry Hunt outlined the first clear statement of the anticlinal theory of the accumulation of petroleum, but during the next 25 years Hunt and the other geologists who accepted the anticlinal theory made little application of it in reporting on the oil possibilities of certain areas in the United States and Canada. In the early eighties I. C. White made practical application of the principles of the theory in the location of new oil and gas fields, but still the industry in general continued to ignore geology. From 1900 to 1915 the significance of the relation of petroleum to anticlinal structure was clearly demonstrated for many areas by the investigations and publications of the Federal Geological Survey.

The number of geologists now serving the industry in the United States, in the employ of companies and in the employ of governmental, State, and other institutions, appears to exceed 3,000—a number somewhat larger than the number of geologists in the United States who are members of the American Association of Petroleum Geologists. Altogether, 2,354 geologists living in the United States were members of this organization on March 1, 1938.

It is noteworthy that the States having the greatest oil production are the ones that have most oil geologists, as indicated by the membership of the American Association of Petroleum Geologists as of March 1, 1938.

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Texas, ranking first in production—510,318,000 barrels of oil in 1937—has 868 geologists; California, standing second—238,521,000 barrels of oil in 1937—has 314 geologists; Oklahoma, standing third—228,839,000 barrels of oil in 1937—has 430 geologists; Louisiana, standing fourth—90,924,000 barrels of oil in 1937—has 124 geologists; Kansas, standing fifth—70,761,000 barrels of oil in 1937—has 134 geologists. In these five States there is 1 geologist for every 600,000 barrels of oil produced in 1937.

METHODS EMPLOYED BY THE PETROLEUM GEOLOGISTS

The oil geologist, in the application of his science to the recovery of petroleum, has a wide field of opportunity before him and he makes use of facts and conclusions from many phases of geology, including structure, stratigraphy, paleontology, sedimentary petrology, sedimentation, geomorphology, and metamorphism. In his search for, and his location of, oil deposits he has from time to time abandoned or modified old methods and has adopted new methods of exploration. The available time will not permit the presentation of a full list of these methods; it will permit no more than brief mention of some major developments during the present century. Important developments during the early years of the century were the adoption of the structure contour to portray the structural features of prospective or producing oil and gas areas and also the application of the plane table and alidade as instruments for determining accurately the altitudes of the "key beds" that were contoured.

Airplane photography, first employed during the World War, was utilized about 1920 by the oil geologist. Subsequently its utilization by governmental agencies and by oil and other companies has increased rapidly, and at present about half the area of the United States has been covered by aerial photographs. To the geologist such photographs record a wealth of essential details of geologic features that are not obtainable by any other method of mapping. As the years pass, he relies more and more on such pictures and employs fewer and fewer plane table maps.

Surface structural mapping reached its peak application between 1920 and 1925, and it has thus for many years occupied a place of decreasing importance in the search for new oil fields. This decline is attributable to the gradual decrease in number of favorable structural features that can be recognized by surface geologic mapping.

Core drilling for the determination of structure was introduced in the United States in 1919 and was employed on an extensive scale for many years in portions of the midcontinent region.

The microscopic examination of well cuttings was begun on a large scale in 1917 and since that time it has reached a place of fundamental importance. To it the oil geologist now gives about half of his effort.

The practice of obtaining cores of oil sands and other important beds in order that their character may be accurately noted is used in all producing areas. The microscopic study of insoluble residues obtained by dissolving in hydrochloric acid well cuttings of limestones and dolomites was begun in 1924 by H. S. McQueen (10). It has been successfully utilized by the oil industry in the midcontinent region—from Ohio and Tennessee on the east to Kansas and New Mexico on the west—for the determination of underground stratigraphy and structure.

Micropaleontology, first introduced in universities and also by companies to a limited extent as early as 1919, became an integral part of the oil business in the United States in 1924.

Geophysical methods, magnetic, gravimetric, electrical, and seismic, are widely used in the United States by the oil industry as a means of locating and mapping buried structural features. The adoption of the seismograph followed the discovery of its applicability during the World War for locating long-range guns. In its use by the oil industry the long-range guns are replaced by explosive charges in prospective oil localities. The first applications of gravimetric methods in the detection of anticlinal structure in this country were made in 1917 and 1919 by the Coast and Geodetic Survey when stations on Damon Mound, Tex., and Paleozoic folds in Maryland were occupied at the request of David White of the Geological Survey (22). In 1924 oil companies located three salt domes by geophysical methods, the Nash dome by means of the torsion balance, the Orchard dome by the seismograph, and the Long Point dome by both the torsion balance and the seismograph. Since 1924 a total of about 100 salt domes in the Gulf Costal Plain and many other structural features from New York to California have been found by means of geophysical methods.

A type of well record or log, known as an electrical log, was developed in 1928. This type of well record is a great aid in exploratory drilling and the exploitation of oil fields. It shows the electrical resistivity and the relative porosity of the beds passed through by the drill. It permits the identification of oil- and water-bearing sands and gives useful information concerning the character of the beds. This information, in many areas, is more accurate than that provided by sets of cuttings.

PROGRESS OF PETROLEUM GEOLOGY

The progress of the science of petroleum geology is revealed in many publications, particularly those of the Federal and State Geological Surveys and the American Association of Petroleum Geologists. This Association was organized in Tulsa, Okla., in 1917 with a membership of 94 and now (December 1938) has a domestic and

foreign membership of about 3,000—a number greater than that of any other geological society in the world. The association issues a monthly bulletin containing about 150 pages in each number, and in addition it has issued 12 special volumes. The reports of the Federal and State Geological Surveys dealing especially with petroleum geology are numerous and constitute a major portion of the literature on the subject.

An important factor in the development and progress of petroleum geology has been the mounting store of geologic data supplied by wells that have constantly increased both in number and depth. The number of wells that have been drilled for oil and gas in the United States exceeds 900,000. The world's deepest well, completed this year in the southern San Joaquin Valley, Calif., reached a depth of 15,004 feet. This well is nearly 9,000 feet deeper than the mine workings (slightly more than 6,150 feet) of the Quincy Mining Co., Hancock, Mich., and is about 6,500 feet greater than the 8,530-foot workings of one of the Crown Mines on the Rand. The producing zone of this deep California well is from 13,092 to 13,175 feet, but a more recently completed well of the Fohs Oil Co., in Terrebonne Parish, La., is producing from a slightly greater depth—namely, 13,254 to 13,266 feet.

CONTRIBUTIONS OF PETROLEUM GEOLOGY TO GENERAL SCIENCE OF GEOLOGY

Petroleum geology, because of its wide field of opportunity for the investigation of geologic conditions on the surface and also geologic conditions to the depths penetrated by wells—15,004 feet—and to the depths reached by geophysical methods—more than 30,000 feet—has made notable contributions to the general science of geology. Some of the more important contributions will be mentioned briefly.

Anticlines, as already noted, were first sought as favorable structural features on which to locate drilling sites for oil; but, with further drilling and the consequently increased knowledge of the occurrence of petroleum, it was learned that oil occurs not only on simple anticlines but also on many other types of structural features which include terraces, anticlinal noses, faults, unconformities, salt domes, lenticular sands, and buried hills.

Buried hills and the superposition of surface anticlines over them were brought to the attention of geologists by Sidney Powers (13) following the discovery of granite hills underneath the Eldorado line of folding in Kansas and of hills of Ordovician rocks underneath the Pennsylvanian sand production at Healdton, Okla.

Our knowledge of the geology of the salt domes in Louisiana and Texas has been revolutionized in the last quarter of a century. Now the domes are generally regarded as intrusive plugs of salt that moved

upward from bedded salt of probable late Jurassic or early Cretaceous age. The salt is believed to have moved upward as much as 30,000 feet in the coastal portions of Louisiana and Texas. Formerly the salt masses were believed to have been formed as a result of volcanic activity, gas uplift, or the crystallization of the salt along zones of weakness in the rock strata.

The Gulf Coastal Plain may be cited as an example of an area whose tectonic map has undergone great transformation as the result of oil exploration. To the tectonic map of the Gulf Coastal Plain such structural trends as the Mexia fault zone, the buried course of the Ouachita belt of Paleozoic rocks, and the Gulf Coast geosyncline, have been added.

From the determination of the effect of regional structural deformation and the attendant metamorphism on deposits of petroleum and coal in the eastern United States, David White drew, in 1915, a "deadline" beyond which oil may not be expected in the Appalachian and Ouachita regions (22). This oil "deadline," or extinction zone, lies between the 60- and 65-isocarbs, lines connecting points where the coals have 60 to 65 percent of fixed carbon.

Also the composition of the hydrocarbon gases in the northern Appalachian region bears a close relation to the structure and the degree of metamorphism of the associated strata. This has been pointed out recently by S. H. Hamilton (7), Charles R. Fettke (5), Paul H. Price and A. J. W. Headlee (14).

From the measurements of the temperatures of deep wells by Van Orstrand (21) and others in the United States it has been shown that relatively high temperatures are generally associated with faults, salt domes, sand lenses, and anticlines of both large and small closure. It appears that both the local and regional variations of earth temperatures of the sedimentary strata thus penetrated by wells are related to thermal conductivity and to the depth to the underlying crystalline basement. Differential uplift on either a large or a small scale would tend to elevate the isotherms irregularly.

Stratigraphy, of a refined character, has received impetus in consequence of the requirements of the oil industry for exact information concerning the thickness and character of the rock strata of prospective oil regions and of areas under development. This type of information is required for an interpretation of geologic history and for the preparation of precise structure maps. The geologic history has a bearing on the origin and migration of oil and the structure maps may reveal favorable places for its accumulation.

Time will permit mention of only three interesting types of stratigraphic work. One of these is to be found in western Kansas where petroleum geologists have matched the intervals between bentonite beds in the Niobrara chalk in a way suggestive of the matching of

tree rings by archeologists in dating ancient pueblos in New Mexico and Arizona. In this way the geologists obtain extremely accurate data for mapping structure on the surface and in core drilling.

An investigation by N. W. Bass (1, 2) and his coworkers of the shoestring sand bodies that yield much petroleum in Greenwood and Butler Counties, Kans., and Osage County, Okla., has shown that these elongated lenticular sand bodies represent sand bars along ancient shore lines during the Pennsylvania epoch. A study of 22,000 well logs in and near the oil fields supplemented by an investigation of nearly the full length of the Atlantic and Gulf coasts has made possible the mapping of land features and shore lines of the ancient seas as they existed in Kansas and Oklahoma 250 million years ago.

The recognition and determination of changes in facies of sediments occupy the attention of all stratigraphic geologists. Many such changes may be noted in the exposed rock strata, as in the Permian section of Utah and in the Cretaceous section of the Book Cliffs of Colorado and Utah. The most striking and best-known example of such facies changes in this country is offered by the Permian rocks of the Delaware Basin of New Mexico and Texas. The basin was surrounded by a reef zone, and this in turn by a back reef zone. Each of these—the basin and the two zones—is characterized by different kinds of deposits. These relations are exceptionally well displayed in the Glass and Guadalupe Mountains and also by the records of thousands of oil wells in the plains east of the mountains.

Stratigraphic information and also areal geologic maps have been contributed generously by oil companies to State and Federal Geological Surveys for use in connection with official investigations in the petroleum-producing States. The publication of such modern State geologic maps as those of Oklahoma (11), Kansas (12), and Texas (4) was greatly facilitated through the active interest and support of the petroleum geologists and companies in those States. The great stock of information acquired by oil companies in California has been drawn upon in large measure in the preparation of two recently issued volumes—one entitled "Geology of California," by R. D. Reed (15), and the other "Structural Evolution of Southern California," by R. D. Reed and J. S. Hollister (16).

The stratigraphic information supplied by the wells drilled for oil and gas enables the geologist to draw geologic maps of the past. Such maps are areal geologic maps and they thus differ from paleogeographic maps which show the distribution of land and water. An early, and perhaps the first, aerial geologic map based almost entirely on well data was one for northeastern Oklahoma compiled by Luther H. White. It was published in 1926 by the Oil and Gas Journal (23) and also by the Oklahoma Geological Survey (23).

More recently, such maps of Kansas (9), Oklahoma (9), Texas (17), and a large portion of the United States (8) have been published. The deep drilling for oil and gas provides not alone stratigraphic information but also structural data that permit the preparation of subsurface structure maps, both local and regional in character. In the words of R. A. Daly at the banquet of the Geological Society of America in Tulsa, Okla., on December 30, 1931, the petroleum industry has contributed the third dimension to geology.

DEEP DRILLING AND SEARCH FOR PETROLEUM DISCOVER OTHER MINERAL PRODUCTS

The petroleum industry, in its addition of this new dimension to geology, has had an unusual oportunity to discover mineral products that lie deep below the surface. Commercially important deposits of five mineral products thus discovered with the advent of deep drilling and search for petroleum are natural gas, helium, natural carbon dioxide, potash in New Mexico, and sulfur in the coastal areas of Louisiana and Texas. The five industries centering around these may thus be regarded as quintuplets of mother petroleum in the household of the mineral industry. A few vital and other statistics of interest about each of the quintuplets will be mentioned.

The commercial utilization of natural gas, one of our principal sources of light and power, dates back as early as 1821 when gas from a shallow well at Fredonia, N. Y., was used in homes in that village. Our present marketed output of natural gas, amounting in 1937 to 2,370 million cubic feet, comes from 24 States and is transported through 85,000 miles of trunk lines to consumers in 35 States. The known reserves of this convenient and efficient source of heat and energy are, according to R. W. Richards,[3] at least of the order of 100 trillion cubic feet.

Gas wells suitable for producing solid carbon dioxide, known generally as dry ice, have been drilled in Montana, Colorado, Utah, New Mexico, and California; and plants for the manufacture of dry ice from gas supplied by such wells have been constructed in recent years at Wellington, Utah, Witt and Bueyeros, N. Mex., and Niland, Calif. Dry ice is a convenient refrigerant and is being produced in increasing quantities, owing in part to the growing demand for it by transcontinental and transoceanic shippers.

Sulfur was discovered on a salt dome at Sulphur, La., in 1865 by the Louisiana Petroleum & Coal Co. while prospecting for oil. Sulfur production was begun in Louisiana in 1903. To January 1, 1938, 41,163,000 long tons of sulfur valued at over three-quarters of a billion dollars has been produced from the cap rock of salt domes on the gulf coast of Louisiana and Texas. Before the development of

[3] Personal communication.

the Louisiana and Texas deposits 95 percent of the world's supply of sulfur came from Sicily. At present these two States supply the greater part of the world's sulfur and more than 99 percent of the domestic output.

The United States possesses the only known natural gas fields in the world that yield gas sufficiently rich in helium to warrant the extraction of this element on a commercial scale. The richest helium-bearing gases, those containing 1 to 8 percent, are found in southeastern Kansas, southeastern Colorado, eastern Utah, and in the Texas Panhandle. The production of helium on a large scale was born of the necessity to find during the World War a noninflammable substitute for the extremely inflammable hydrogen gas in balloons and dirigibles. The operation of experimental plants in Texas and Canada, beginning in 1918, led to the erection in 1919 of a production plant at Fort Worth, Tex., and later other plants, one by the Helium Co. at Dexter, Kans., in 1927, and the other by the Bureau of Mines near Amarillo, Tex., in 1928.

American potash, like our helium, was first produced during the World War and it now supplies a major portion of our domestic requirements. An energetic search for possible sources of potash in this country began in 1911. One of the possible sources thus investigated was the Permian salt of Texas and New Mexico. Information about the extent and character of the potash deposits in these States acquired from oil company wells and from Government and private core tests revealed commercial deposits of potash in New Mexico. Shipments began in 1931 and they totaled 700,000 tons of crude potash salts in 1937.

PETROLEUM RESERVES OF UNITED STATES

Our petroleum reserves, because of the nature of the occurrence of petroleum, are imperfectly known. Petroleum is a liquid contained in the rocks deep below the surface in many small widely scattered areas. It is discovered by the driller who is aided in his search by the accumulated knowledge about oil and its occurrence.

A number of estimates of the total petroleum resources of the United States were prepared between 1909 and 1921. During this period, however, it became evident that the unproved reserves in unknown fields awaiting future discovery could not be estimated with any degree of accuracy whereas the quantity of oil in the proved reserves, recoverable by then current methods of production, could be estimated with reasonable accuracy on the basis of the past production experience of depleted fields. The first estimate in which the proved reserves were separated from estimates of undiscovered fields was made in 1921 by the Geological Survey with the cooperation of the American Association of Petroleum Geologists. In this estimate

5 billion barrels were classified as oil "in sight" on January 1, 1922, and 4 billion barrels additional as "prospective and possible" and recoverable by current methods of production (19). A number of estimates have been prepared since 1921.

The individual estimates of the petroleum reserves that have been made in 1921 and subsequent years differ somewhat, but they all possess a similar order of magnitude. Since 1930 the estimates of proved reserves have ranged from 10 to 15.8 billion barrels.

The proved reserves in the ground, like the stocks of petroleum held above ground, are constantly changing in quantity. They are depleted by the output of producing wells and increased by the discovery of new fields and deeper pools. During the period 1922 to 1938, for which figures of proved reserves are available, many large fields were discovered so that, notwithstanding the consequent greatly augmented production, the proved reserves have increased.

FUTURE PETROLEUM SUPPLY OF UNITED STATES

The continued discovery of new fields and deeper oil-bearing zones is required to meet future demands, just as it has since the beginning of the industry in the United States. The extent to which new sources of supply are discovered and produced depends upon the payment of such prices by the consumer as will permit the industry to carry the heavy and increasing expense of new exploration and to maintain profits.

Much oil remains to be discovered in new fields and in deeper pools, but the exact location of these fields and the quantity of petroleum they will yield are not known; they will not be known in advance of drilling. Nevertheless, their number, whatever it may be, is definitely limited and each newly found field leaves one less to be discovered.

The answer to the question "When will the day of petroleum shortage in the United States be reached?" lies not alone in the supply of oil remaining in the ground. It rests also with the geologist to continue to aid in the increasingly difficult problem of discovery, with the engineer to improve drilling technique and to increase recoveries, and with the chemist to continue improvements in refining practice. In part, it rests on the price that the public can pay in the future for oil products, and that in turn depends in part on increased efficiency in use. In a large measure it rests on conservation and efficiency in the discovery, development, and production of our future oil fields.

The future undoubtedly will see continued advances in science and technology affecting the discovery, recovery, refining, and utilization of petroleum. Thus far, these advances have enabled

us to keep supplies ahead of needs, but they afford us no assurance that the same record can be maintained indefinitely.

In this connection it is of interest to call attention to some of the concrete accomplishments of recent years. The recovery of gasoline from a barrel of oil has more than trebled in the last 40 years—from about 5½ gallons in 1899 to about 18½ gallons in 1937. In the 15-year period from 1922 to the end of 1936 the geologist and the petroleum engineer have aided the driller in the addition of 10.8 billion barrels to our petroleum reserves, despite the production of 12.8 billion barrels during that period. Also, from 1920 to the end of 1936 the chemist, by the introduction and improvement of cracking processes, has conserved 8.5 billion barrels of crude oil (20). The petroleum engineer is meeting energetically the challenge to recover the 65 to 85 percent of oil remaining in the ground after a field no longer yields oil by the older methods of production. Each year witnesses the improvement and extension of recovery methods, such as acid treatment and repressuring by the introduction of gas, air, and water into the oil-bearing zones. The increased adoption and refinement of such methods in areas where geologic and other conditions permit their use will lead to the recovery in places of 50 percent or more of the total oil content of the producing zone.

Moreover, when a shortage of domestic crude petroleum arrives and there is a consequent rise in prices of petroleum products, substitutes will be drawn upon just as they are now drawn upon to some extent in some countries that are supplied with little or no oil resources. Some of these substitutes are oil products from coal and oil shale, alcohol from farm products, and gases from wood. Our future resources of coal and oil shale have been so determined by geologic evidence and exploration that we know their approximate extent and quantity. According to Dean E. Winchester (24), the oil-shale deposits of the United States will yield 92,144,935,000 barrels of oil, if and when the price of oil permits. Should coal be called upon to supply the demands now met by oil and gas, the coal reserves of the United States would, according to independent estimates by T. A. Hendricks[4] and Arno C. Fieldner (6), last about 2,000 years. These two estimates are based on the assumption that the consumption of energy from mineral fuels will equal the maximum rate of consumption in the past (approximately 23,400 trillion B. t. u. in 1929) and also are based on the assumption of a 30 percent loss of coal in mining. Concerning the cost of motor fuel substitutes, Doctor Fieldner (6) comments as follows:

> Reliable information on the cost of making gasoline from coal in British and German plants is not available, but it is believed that it is three or four times

[4] Personal communication.

the present cost of producing gasoline from petroleum in the United States. These costs will be reduced by further research, but no other liquid motor fuel, whether it be from coal, oil shale, or vegetable matter, can hope to be as cheap as our present petroleum fuels.

The following significant statement on this subject is contained in a recent press memorandum of the Department of the Interior relative to the work of the Bureau of Mines (October 24, 1938):

By the time that depletion of our petroleum resources reaches the point when a motorized Nation must begin to look to other sources for some of its fuel, it is hoped that motor fuel can be supplied from coal so efficiently and cheaply that the transfer can be made from the old fuel to the new without drastic adjustments.

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BIOLOGIC BALANCE ON THE FARM

By W. L. McAtee

U. S. Biological Survey

[With 2 plates]

Biologic balance is the term heard today for what yesterday was called the balance of nature. Some would so closely associate the condition with yesterday, as to deny its present existence. That is, however, not exactly what they mean. What they really have in mind is that the primitive balance of nature such as obtained in America in precolonial times has been destroyed by civilized man and under his domination cannot return.

That may well be, for in all probability man's abrupt and wholesale remodeling of the landscape and his ruthless interference with its plant and animal inhabitants can never be assimilated into nature's more deliberately adjusted system of checks and balances. No sooner, however, does man's disturbing influence anywhere cease than recovery begins.

Unless all fertility has been swept away, bare ground is soon occupied by weeds. Grasses come in next and if there is enough moisture they are followed in time by shrubs and trees. Cut-over woodland, if not too much damaged by fire, will produce a new crop of trees in a human generation. Practically all of the deciduous forest in the eastern United States is this so-called second growth—a vast tribute to nature's power of recovery.

Where a little herbage is established, insects will be attracted, and soon birds will drop in to snap them up. When the grasses and weeds make a fair crop of seeds, mice will come to take toll, and when there are enough mice, weasels will prey upon them. Juicy greens and the tender shoots and bark of shrubs will draw cottontails, and in turn the bunnies attract foxes.

None of these things happen suddenly, nor until the way has been prepared for them. They come about in a gradual and orderly manner, that is, naturally, in the truest sense of the word. As a philosopher once put it, "Nature abhors a vacuum," but these hard words mean, in the present connection, only that life pushes in anywhere it has a chance. All life provides food for other life, and it

is evidently a natural law that no food supply is left untouched. Further, the natural law seems to decree that although all food supplies may be utilized, none may be utterly consumed.

It is a general habit of animals to sample foods here and there; rarely do they make a clean sweep of anything. This habit contributes to biologic balance, as the toll taken is not so great but that the remainder is sufficient to maintain the food species in about their average abundance. Thus the greenery about us looks much the same from year to year; the insects dependent on that foliage neither increase nor decrease except sporadically; and birds that prey upon the insects maintain their average numbers.

These things speak eloquently of biologic balance, and there is a reason. Nature, while tolerant and slow, is inexorable. If a species too largely consumes its food supply, its own numbers will decrease. It may live comfortably on "interest" for years, but let it eat into the "principal" and its own account in the bank of life will soon be overdrawn.

The workings of nature's balance are evident not merely in a broad sense but also locally. In fact natural law is the summation of local happenings. Living things, as a rule, are very localized; as to plants the condition is obvious, but it is likewise true that individual animals do not range widely. Migrants are an apparent, rather than a real, exception, for individuals and groups keep to certain areas in both summer and winter homes; even their migration routes are relatively fixed. In general, territorialism rules, and it contributes a great deal toward balance.

Territorialism is the name we have for nature's system of parceling out places to live. An individual plant occupies a comparatively small territory—that traversed by its roots and branches. Usually, conditions are not so uniform but that some other plant is a little better fitted to occupy an adjacent nook, whether made by vertical or horizontal variations in soil or moisture. Mixtures are the rule, pure stands the exception. Each plant draws certain substances from the soil and adds others to it, thus maintaining average fertility. To resume the banking metaphor, demands and repayments by each living thing are different, but in the long run a fair balance is struck.

In contrast to plants, animals seem very free-moving, but even their movements are limited. The territory of a pair of small birds in the breeding season may be less than an acre in extent, and a family of bobwhites may never range more than a quarter of a mile. Mice may be restricted to a fraction of an acre, squirrels to a radius of a few hundred yards, and cottontails to from one to several acres. In general, the larger the animal the more extensive the territory; but in no event is the individual range indefinite.

Territories seems to depend upon the degree of intolerance animals have for their own kind. When the bounds are overstepped, conflict soon results and the trespasser, as a rule, retires to its own domain. The result is that creatures are confined almost as by a fence, inside of which they must comport themselves so as not to spoil their own living. If they materially damage the range, it will then be lost to their species for a time. With such a system in operation almost everywhere, it is apparent why natural balance usually prevails, and why if disturbed it tends to return to equilibrium. Unbalance automatically brings correction.

Balance results from equalization of opposed forces, and in nature these may be conceived of as a tendency for life to remain localized and hold its place, offset by another under which it spreads and fills any unoccupied habitat. The former leads to the holding of territory, the latter to pioneering, and as a result of their interweaving, the woof of life always pretty well fits the warp of environment. This is certainly balance.

The web is woven only as life is sustained by air, soil, water, and other life. In the realm of sustenance also, balancing factors prevail. Where there is food, something will come to feed on it. If feeding goes too far, the feeders must retreat. Under natural conditions consumption is more or less in proportion to the supply and does not materially encroach upon it. That is balance.

Where encroachment is noticed, it may usually be traced to some unnatural condition produced by man. That is unbalance. Wherever there is unbalance, nature seeks to correct it. Balance, if not always evident, may be said to be ever imminent.

When, regardless of change, a working balance becomes established, it may be at a new level, and whether on that level it is advantageous or not to man depends greatly on what man has done. If, for instance, he has practiced clean farming to the extent that there is little nesting cover for birds, there will, nevertheless, remain sufficient cover for insects and they will increase. Their own internal wars will produce some sort of balance, but it will be at a higher level—there will be more insect mouths to feed. The farmer will have given aid and comfort to the enemy. If he allows the fertility of the soil to fall, as by uncontrolled erosion of the loam, the inhospitable subsoil will support fewer and less desirable plants. Vegetation will do its best to reoccupy the land, but for a period the plant cover will be sparse and weedy and will support little animal life of value to the farm. The web of life is stretched thin to cover a barren place. There may be balance but it will be at a lower level than before. If destructive influences cease, conditions will improve slowly under nature's management, though more rapidly under man's, if he will

but make the effort. Enrichment instead of depletion of environment should be his conscious goal; and when that ideal steadily prevails, there will be a different, a far more satisfactory tale to tell of man's progress in getting along with nature.

The phrase "balance of nature" admittedly is a figure of speech, but it is a justifiable one. Balances always tip up and down before they equalize. The balance of nature is such a tipping balance because all animal and plant populations are ever fluctuating. But just as truly as does a weighing balance, that of nature seeks equilibrium.

This is no more difficult to understand than if the grass is scanty here and lush yonder, grazing animals will feed there; automatic equalization takes place at once. If sumac bushes along the edge of the woodlot are shaded out, cottontails, which feed so much on their bark, may have to leave the dying thickets and come perchance to a hedge near the garden where they may do damage. If mice in grassland are killed by burning, weasels that would prefer to feed upon them may be forced to look elsewhere for food, possibly in the chicken-yard. If some isolated, densely branched, and prickly trees, as thorn-apples or red haws, are preserved or grown, kingbirds will build their nests in them and from these airy castles harass crows, hawks, and buzzards, so that they no longer can do as they please; the kingbirds will also consume thousands of insects during the summer.

The operations of nature's balance are going on before our eyes all the time. To realize it we need only to take a little thought as to causes and effects. Everything that happens has a cause and produces an effect, and these effects in turn become causes. The far-reaching effects of a hard winter or of a drought are familiar examples. As a result of such climatic severities, trees may die at once or be so injured that they succumb later. Every tree that perishes has been host to many kinds of insects that must then find another home or die. The insect populations have regularly paid an endurable toll to various predators and parasites. These must now levy their tax elsewhere or cease to exist. The trees that die have shaded the ground; now the sun strikes through their leafless branches stimulating to rapid growth plants previously suppressed and seeds that have been waiting, possibly years, for this opportunity to sprout, grow, and reproduce their kind.

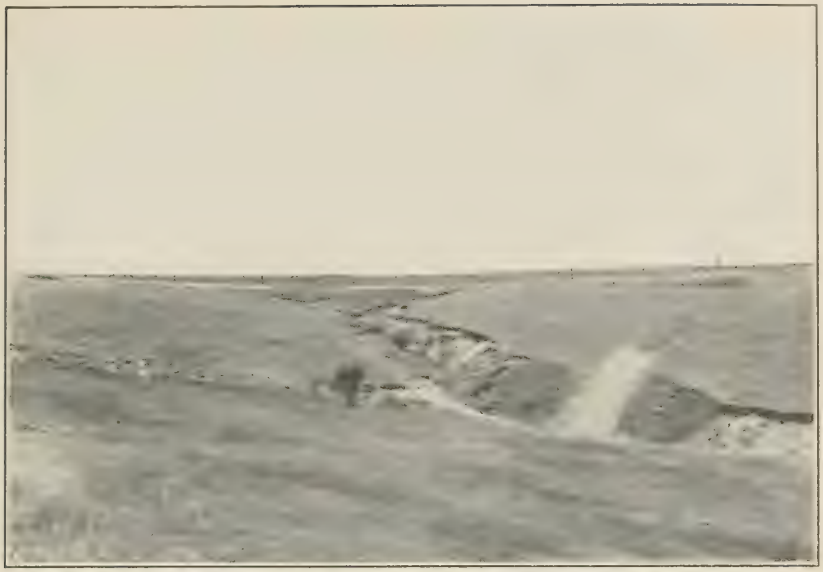
Each new thing attracts a company of dependents, so that under the dead tree a plant and animal society very different from that previously dominant may come to rule. The lifeless bole and branches themselves provide homes and food for fungi, insects, and other organisms that could not successfully attack the tree in life. Each being in the association depends upon others, and prepares the

way for still others. This is just as true of the farm as of the woodland; a source, perhaps difficult to trace, may have a great result, though acting through a number of links in the chain of cause and effect. Such a series is like the file of wooden soldiers familiar in childhood; let one topple and down go the rest. To return to the warp and woof metaphor, the web of life is so involved that no thread may be added, none withdrawn, without in some degree affecting the whole pattern. No wonder then that man's usually unconsidered and ruthless alterations lead to unfortunate results.

Observation teaches that natural balance, like good housekeeping and good husbandry, is guided by the rule of "A place for everything and everything in its place." It takes every kind of place or "habitat" natural to an area to insure the presence of all factors necessary to working of the biologic balance. The farm that keeps all natural nooks and produces wildlife food and cover as widely distributed and abundant as compatible with successful farming will come nearest to attaining the biologic balance that is so necessary to wild creatures, and so beneficial in maintaining the farm. In the light of the balancing principles of holding territory and pioneering, it is encouraging to the individual landholder to realize that attractive territories for numerous kinds of wildlife can be established entirely within the boundaries of his own place, that he can successfully practice wildlife management whether his neighbors do or not, and that the keenness of wildlife in finding all favorable places insures that the territories he preserves or creates will be found and occupied.

The farmer who, as far as possible, preserves natural conditions and encourages biologic balance, contributes not only to his own welfare but also to that of the nation.

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Courtesy Soil Conservation Service.

1. GULLY EATING UP GOOD TAMA SILT LOAM.

Almost a desert for wildlife. Marion County, Iowa.



Courtesy Soil Conservation Service.

2. SAME GULLY 2 YEARS AFTERWARD, STABILIZED WITH TREES, SHRUBS, AND GRASSES.

An oasis for wildlife.

REVEGETATING ERODED AREAS CONTRIBUTES TO BALANCE



Courtesy Soil ConservationService.

1. LEFT, UNGRAZED, RIGHT, GRAZED WOODLOT.

A feast for wildlife in one, a famine in the other. Mecklenburg County, Va.



Courtesy Soil Conservation Service.

2. TREES, WORM FENCES, AND STRIP CROPPING GO TO MAKE THIS WELL-BALANCED FARMING COUNTRY.

Its diversity provides homes for a variety of wildlife. Muskingum County, Ohio.

UNBALANCE AND BALANCE ON THE FARM.

ON THE FRONTIER OF BRITISH GUIANA AND BRAZIL[1]

By Capt. H. Carington Smith, R. E.

[With 4 plates]

British Guiana, between Venezuelan Guiana and Surinam, or Dutch Guiana, on the Atlantic seaboard, has an area of about 90,000 square miles, divided into the coastal alluvial plain, the central sand and clay belt, and the mountain plateau. The coastal plain, from 10 to 40 miles wide, contains practically all the towns, villages, population, and cultivated land. It is flat and low, scarcely rising to 50 feet above sea level, while along the coast much of it is actually below high-tide level, necessitating sea defenses and intertidal drainage. The sand and clay, or center, belt is covered with dense tropical forest, and has an average elevation of about 200 feet above sea level. It is uninhabited except for a few lumber camps and bauxite, gold, and diamond workings.

The mountain region rises to the watershed of the Amazon, culminating in the southwest in the Roraima massif 8,600 feet high and in the south in the Akarai highlands, which contain mountains touching 3,000 feet, though for the most part the land averages only 1,000 feet above sea level. This belt is also covered with dense tropical forest, except for some savannas or grasslands to the southwest, which make fair cattle country and are sparsely inhabited. While every available cleared acre of the coastal plain is under cultivation, this amounts to only a three-hundredth of the colony, the rest, except for the small savanna lands, being impenetrable forest. Owing to this unbroken extent of forest, the rivers form the only means of communication in the interior, or did so until the advent of the amphibian airplane, the use of which is very limited owing to the scarcity of stretches of river on which it is possible to alight.

Until 1835 very little was known of the interior. In that year Sir Robert Schomburgk, on a commission for the Royal Geographical Society, made extensive river surveys. Among other journeys he ascended the Essequibo to its source, crossed the watershed and traveled down one of the tributaries of the Amazon and up another, recrossing the watershed near the source of the Courantyne, by which he returned to the Atlantic coast.

[1] Reprinted by permission from The Geographical Journal, vol. 92, No. 1, July 1938.

In subsequent years the savanna lands in the southwest were penetrated by settlers, more from the Brazilian side than from the British, and the Essequibo and Rupununi Rivers became fairly well known. Balata bleeders ascended the Courantyne as far as Wonatobo Falls, and a few hardy pioneers, including Barrington Brown, explored the upper Courantyne and its tributary, the New River; but for the most part very little was known of the southeast corner of the colony.

In 1901 a treaty was concluded between Brazil and Great Britain whereby these countries agreed to survey and demarcate their common boundaries, defined as follows from geographical information then extant: From Mount Roraima eastward along the watershed to the source of the Ireng River; down the Ireng to its junction with the Takatu River; up the Takatu to its source at Mount Wamariaktawa and thence eastward along the watershed between the tributaries of the Amazon and the several rivers draining British Guiana to the source of the Courantyne. The Venezuelan and Dutch boundaries were also defined. His Majesty the King of Italy was to act as referee.

However, it was not until 1930 that field work began. In the following year a commission, set up by the colony itself, met Brazilian and Venezuelan commissions at Roraima, the western trijunction point. This point was fixed and the survey of the Brazilian boundary was commenced.

On the west side of the colony the mountain plateau drops abruptly to the sand and clay belt in a rock escarpment 1,000 feet high. The rivers draining the plateau and the foothills of the Roraima range plunge over this shelf in falls rarely equaled for height or beauty, the best known being the Kaiteur Falls on the Potaro; there are many others, some higher, but none of such perfect proportions of volume and height.

To reach the Kaiteur Falls from Georgetown used to mean a 7-day journey by steamer and motorboat. This is now reduced to 3 days by overland transport between Bartica and Garraway Stream, a small settlement on the Potaro; but the most convenient and impressive route is by air. The flight takes 2½ hours, and the plane alights on the river above the falls. The take-off for the return flight is an experience itself, for the plane taxis down the river and takes off over the brink of the falls. At one moment the machine is flying 100 feet off the water, the next it is 900 feet up over the mist-filled gorge. It continues down the gorge shut in on either side by steep green cliffs streaked with the white streamers of cascading forest streams.

The line of communication of the first commission leading to Roraima went up the Potaro, and these falls presented an obstacle of the first magnitude. All stores, instruments, rations, and the materials for building boats to navigate the upper river had to be carried over

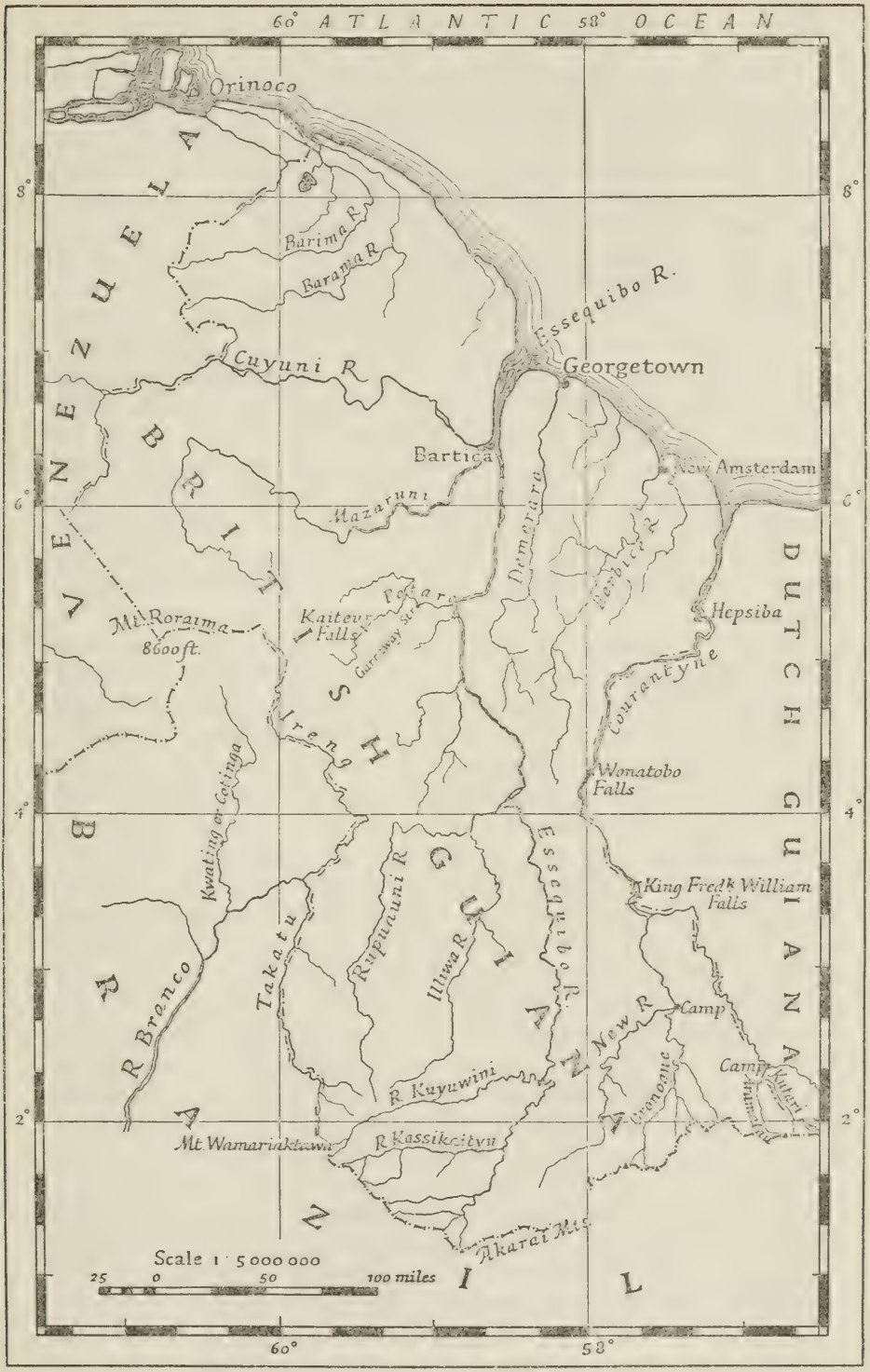


FIGURE 1.—Sketch-map of British Guiana to illustrate the work of the British Guiana and Brazil Boundary Commission.

the portage and up the 1,000-foot escarpment by manpower. It is to be hoped that the work of the first commission will some day be chronicled. The fact that the boundary which they surveyed lay largely along rivers made their survey technique and the difficulties which they encountered rather different from those of the second commission. In 2½ years' work they reached the headwaters of the Essequibo and were exploring the Courantyne and New Rivers with a view to opening them up when a major tragedy occurred. Most of the officers and some of the men developed beriberi, a disease usually due to certain diet deficiencies. The cause of this disaster is a mystery, for the diets of both officers and men were apparently well balanced. One theory which has obtained considerable weight attributes the outbreak to local deposits of pitchblende which impregnated the water. It is of interest to note that the worst and majority of cases occurred in the officer ranks, in spite of their higher standard of living as compared with that of the men. In the face of such a catastrophe there was no alternative but retreat, which was carried out at the beginning of 1934, but not before several lives had been lost.

In the following year the Colonial Office took over the administration of the commission, and in July 1935 three officers and four noncommissioned officers of the Royal Engineers arrived in Georgetown and commenced preparations for the following season. While a small advance party under a native boat captain ascended the Courantyne to recommission the boats and engines and recover the stores left at the portages by the former commission, frantic preparations went forward in Georegtown. One of the first problems was the recruitment of labor. The colony has a population of 300,000 composed of very heterogeneous elements. Originally inhabited by Indians of whom only between 6,000 and 7,000 survive today, it received a large influx of African Negroes in the slave trade days, and today they account for 40 percent of the total population.

In 1850 East Indian apprentices emigrated to the sugar estates on indenture, and their numbers now equal or slightly surpass those of the Negroes. The remainder of the population consists of about 10 percent mixed and non-European, including a large number of Chinese, and about 6 percent of Europeans, three-quarters of whom are Portuguese.

The laborers of the commission were recruited principally from aboriginal Indians and Negroes, in about equal proportions. The Indian is a likeable fellow. Dignified, reserved, and quiet, he is a good bushman and a keen naturalist, though his small stature limits the load he can carry, and he becomes discouraged and morose

quickly. He is usually a good axman, a fair hunter and boatman, and is very handy at constructing huts and camp furniture from local materials. The majority are intelligent, and have a very keen perception and a sense of humor. A few of them who had come into contact with mission schools could read and write a little, and only one or two could not understand pidgin English, the lingua franca of the colony. No Indian willingly accepts the responsibility of leadership or authority over his fellows; they prefer to work as a soviet, none giving orders but each doing his particular job in mutual but silent agreement.

The Negro has an entirely different character. His strength enables him to carry the heavy load, but he is of childish mentality, quick of temper, excitable, and delights in nothing better than making a great noise about nothing. Some were good axmen and watermen, but the majority were not at all at home in the bush and grumbled continually. There were, however, notable exceptions. A few drawn from the independent farmer class were splendid all-around men and better than any Indian. Blacks and Indians worked together more or less in harmony, but usually lived in separate tents by choice. Such different characters are not belied by physical appearances. The black's negroid countenance and curly hair are in striking contrast to the straight hair and Mongolian features of the Indian. The Indian has rather finely shaped feet and ankles, but the black stands splayed and firm on large, shapeless pads of gristle.

At a preliminary conference the Brazilian, Dutch, and British sections arranged to rendezvous at the eastern trijunction of the Brazil-Guiana boundary as soon as possible after the close of the wet season in August. The Dutch started upriver in a fleet of canoes propelled by paddlers in July. The British followed in August by motorboat.

A camp was established at the head of deep-water navigation at Hepsiba, 50 miles from the coast. It soon became apparent that the most difficult and expensive part of the commission was going to be the transportation on the line of communication—the movement of personnel and stores from the coast to the boundary.

From a geologic viewpoint the rivers of British Guiana are not rivers at all, but simply large streams flowing through the bush in shallow rock and sand channels. There are no river valleys proper, the banks of these channels being only a few feet high and the topography along either side indistinguishable from that of anywhere else. The country is intersected by a series of parallel out-cropping rock reefs running east and west, over which the rivers flow in swift rapids.

An annual rainfall of 100 to 140 inches concentrated largely between the middle of May and August causes great variations in the volume of run-off. Seasonal variations of as much as 30 feet were measured quite far inland, and rises of 4 feet in a day were not uncommon. During the rainy season the rivers became rushing torrents carrying all before them and flooding the bush on either bank. At the end of the dry season, on the other hand, navigation is difficult and slow owing to lack of water. The keels and bottom planking of the boats soon wear out or become stove-in by frequent groundings, and propellers are often damaged.

Stores and personnel were brought to Hepsiba by a schooner which once a month beat down the coast against the trade winds and sailed up the river. Here the cargo was transhipped to bateaux driven by 10-horsepower outboard motors and manned by a crew of paddlers for emergency. Constructed of greenheart with mora frames, the bateau is remarkable for its stability, handiness, and toughness. Not having a deck, it is very resilient and can absorb an enormous fore-and-aft twist. It is steered by a large paddle lashed to the stern and another manipulated by the bowman. This double leverage acting on the hull of small keel depth and long overhanging prow produces a very quick turn, necessary when descending swift and tortuous rapids.

In ascending the river, the bateau is laboriously hauled over the rapids by warps. This requires a crew of anything up to 20, depending on the state of the river. First the cargo is off-loaded and portaged to the top of the fall, then the bow and stern line and the warp are run out, and the boat is hauled up inch by inch against the rushing water. At the top it is reloaded, always a lengthy process, and the journey proceeds to the next rapid, probably less than an hour's steaming distant. At low water a day may be taken to negotiate one rapid less than 2 miles long, the crew camping exhausted at the top at nightfall. Thus transportation is not only precarious, but exasperatingly slow.

Descending the river the labored slowness of the upward journey is replaced by a swift journey of thrills and exhilaration. The rapids are run with engines full ahead to give steerage way, and paddlers keep blades poised ready for the command of the captain. The bowman streams with perspiration as he struggles with his large paddle, first one side, then the other, at the same time trying to maintain his balance on his precarious foothold. Submerged rocks are indicated by the whirl of water below them. The captain must pick his line and think and act quickly, much as the rider following hounds does, or the skier making a difficult descent; but unlike these

sportsmen he cannot stop. To act too late means being stove-in and sunk in the swift water. Rapid-running as a sport, especially in a canoe, is almost unequaled. The Courantyne contains two falls or large rapids so swift and high that their passage is impossible, one at Wonatobo and the other at King Frederick William. Here it was necessary to establish intermediate camps and to portage baggage overland by gangs of men.

When the river becomes too small for the bateaux, dugout canoes or corials continue the communication. The construction of these craft is a skilled job only understood by some Indians. First a suitable tree is found and felled. The log is cut to length, flattened on top, and tapered at the ends by a broad ax. Then it is hollowed out by adz, leaving a shell about 1½ inches thick. A fire is then kindled below the whole length and later in the hollow. When everything is hot and steaming, pointed sticks are sprung athwartships into the hollow, forcing the gunwales apart and at the same time drawing the ends up. Thwarts are then added to retain the shape, and sometimes plank gunwales to increase the freeboard. The finished article is a strong, serviceable craft, surprisingly stable and easily handled. These canoes, carrying 500 to 1,000 pounds of cargo, penetrated the creeks toward the source till they would no longer float and had to be dragged by men wading.

Where the river narrows to a creek so that the forest roof closes overhead, the real difficulties of river transport begin. The channel is completely blocked every 50 yards by a fallen tree. Trees growing along the bank invariably fall inward owing to the scour of the stream. In the course of time the sapwood rots away, leaving the heartwood or tacuba, which apparently lasts forever when submerged from the attentions of parasites. These trees must be cut with ax and saw to allow a passage, and as much of the cut is done under water it takes a long time. A day's hard work may produce less than a mile of progress, nor is the job then by any means finished. A week later the water level has changed by several feet. Logs which spanned the creek well above water and allowed the canoes to pass beneath are now awash and have to be cut; or a series of formidable obstacles, formerly deep below water, are revealed and block the way. And so it goes on, ax and saw being as indispensable to the canoemen as their paddles.

Above canoe navigation everything was carried by manpower. The British Guiana Negro, unlike his African cousin, cannot "head-carry," but slings his load from the shoulders in a wickerwork frame called warishye or paneçu. His working load is thus only about 70 pounds, although some stout fellows habitually managed more; 70 pounds for 5 miles was a standard day's work for carriers.

It is not surprising then that the line of communication was a source of constant anxiety and a tremendous item in the expenditure of the commission. Every man on the boundary had to be maintained by five or more men on line of communication. On occasions when there was a shortage of labor from sickness or other causes, and when boatbuilders worked overtime to repair damaged bottoms, it is no exaggeration to say that the commission would have had to stop for want of rations if air transport had not been used.

The commission was fortunate in obtaining the services of Arthur Williams, a free-lance American pilot operating a small flying boat on tourist flights and the transport of diamonds and gold out of the interior. Both plane and pilot were ideally suited to this dangerous and arduous task, and Mr. Williams never stinted his efforts to "run his freight." An airport was established at Wonatobo, the first major portage, and the journey from there to Aramatau Camp was reduced from the 3 weeks taken by boats, even under the most suitable conditions, to 2 hours and 20 minutes. The plane carried only 1,000 pounds in addition to pilot and flight mechanic. Two trips a day were made in favorable weather, the start being at dawn and the final return often during the last 10 minutes of daylight. The day's work was then over for everyone except Williams and his mechanic, Harry Wendt. After dinner they would often work till midnight tuning the engine and servicing the hull.

No praise is too high for these two intrepid airmen. Landing at Aramatau Camp in the confined upper river was thrilling, but the take-off went to the extreme of being unpleasant. The river here is so narrow that to turn the plane on the water required the mechanic on the wing tip; before he had a chance to scramble to the cabin the machine was taxiing on the step, and as he settled into the seat it took off. The 80-foot bush fencing a bend in the river was charged with complete unconcern, and just when the unfortunate passenger had abandoned all hope and got as far as regretting past economies, the plane rose to it like a good hunter, and flattened out above. The proximity of stalling speed was betrayed by the cloud of dust which floated up from the floor of the cabin.

The open river was always a source of new and ever-changing interest. British Guiana is a fisherman's paradise if his ambition is to land large fish rather than consider delicacy in technique. The tackle consists of stout cord approximating clothesline, a piano-wire trace to resist the teeth of some fish, and a hook reminiscent of a small grapnel. Fish vary in size from the small voracious perai weighing 2 pounds to mudfish as large as 150 pounds. The former, although one of the smallest fish in the colony, is perhaps the fiercest. Short,

narrow, but deep, with a powerful, well-shaped tail, he is armed with two single rows of interlocking teeth reputed to be so sharp and powerful that the removal of a man's big toe is done at one snap. Perai are best caught with a metal spinner, which after some use becomes scratched and dented by teeth marks. They were a source of continual apprehension to the boats' crews when hauling up rapids, and should a shot bird fall in the water it soon disappeared unless retrieved at once. Perai are quite edible, but not a delicacy, and very bony.

Another very fierce and even more fearless fish is the hymara, which inhabits the forest creeks. They average 10 to 12 pounds, are covered with scales as large and almost as tough as penny pieces, and have teeth like the perai, but not so long or close fitting and set in much broader jaws. The body ends abruptly in a rudimentary tail, spoiling otherwise graceful lines. Hymara will go for almost anything, and have been known to attack a crosscut saw. To clean the carcass of a bird over the side of a canoe is to risk losing it and to endanger the hands. Their flesh is firm and tasty, but full of Y-shaped bones. Lukanani are most prized for the pot; but cartabac, looking very like the perai, the graceful koraimai, and, on the lower rivers, the basher are all delicious.

The larger fish are the skeet and lau-lau, skin fish with enormous mouths, armored heads, and grinders in place of teeth. The skeet makes a loud honking noise when caught. The lau-lau is so strong that one hooked at Wonatobo drowned his captor by pulling him into the swift water of a rapid; the unfortunate man had wound the line around his wrist and was never seen again. Two unpleasant fish which must be given a wide berth are the sting ray and the electric eel, or numbfish of the Indian. The spiny tail of the former gives a nasty wound into which poison is injected. The latter gives a powerful electric shock until landed, when he is quite harmless.

Fishing methods include shooting by bow and arrow, a fascinating thing to watch but extremely difficult to do with success, owing to the effect of refraction when aiming and the patience required to stand motionless balanced on a precarious foothold. Chopping fish with a cutlass also requires patience. The victims are lured into shallow water by some noisome ground bait and despatched by a well-aimed stroke of a cutlass after an exciting stalk. The night line is as effective but less spectacular. A fair-sized living sapling close to the bank is stripped, bent down, and hooked on a notched stake driven in the shallow water. The line is attached to its top end and the bait thrown wide. The vicious strike springs the trap and the wretched fish describes an arc at high speed to land far in the bush.

The mammals and reptiles of the river are equally interesting. The waterhass, rather like a large guinea pig, reputed to be the largest living rodent, is occasionally seen swimming. The otter or Indian water dog, noisy and inquisitive, is a fine swimmer with a beautiful pelt. The lucky traveler may surprise a tapir or a puma crossing, or even a small adouri swimming bravely between long rests on a moca-moca leaf or tacuba, in constant fear of being attacked by perai or hymara from below or the cayman on the surface.

The water kamoodie or American python sleeps between meals, his distended body coiled in a nest surrounded by the bones of former repasts. One we shot was over 18 feet long. They are easily killed by a well-aimed bullet in the head, but there is always danger of mistaking the tail for the head when the snake is coiled in sleep. The cayman, in spite of his ferocious appearance, is a great coward; those encountered did not exceed 8 feet from snout to tail, although bigger ones are said to exist on the coast.

The iguana is a truly extraordinary beast, who usually advertises his presence by dropping unexpectedly from a high tree over the river with a mighty splash. His only defensive weapon is his tail, which also propels him when swimming. The iguana lays a clutch of some 24 shell-less eggs, the size of marbles. Both flesh and eggs are excellent to eat when properly curried.

Bathed in brilliant sunshine and bounded by perpendicular green walls of the creeper-hung forest, the river gives a first impression of tranquility. Watch it for some time and one is conscious of the constant movement of teeming life—the pitiless war which is waged day and night for survival. Here a sudden darting furrow betrays the attack of a perai on the smaller fish in the shallows; there a large white heron, until now motionless, pounces on his fishy prey; or a family of otters on the far bank chase some unwelcome intruder, following it downstream with loud doglike barks.

At some seasons of the year a continuous procession of small white and yellow butterflies passes across the river. They emerge from the forests on one side and drifting northwesterly disappear in the forest on the far side. They fill the air for 20 feet above the water as far as the eye can see up and down stream, giving the effect of a mild snowstorm. Where they go and from whence they come is a mystery, but they are always headed northwest.

The forest itself is not at peace. Aloft the trees sag under their weight of creeper, trees and parasites struggling to present their leaves to the sunshine. Where the last floodwater has washed away the bank, the cross section shows a solid snarl of roots, twisted,

knotted, and contorted in the fight for moisture and air. The palisade of moca-moca stalks vibrates slowly in the inshore current. On the broad leaf of one, 50 ants scurry in hysterical confusion; they have gained the leaf by swimming from their nest, which, dislodged from above by a falling branch, now floats downstream. In twos and threes they leave the leaf and strike out for the bank, their ranks being steadily depleted by the attacks of little fish from beneath.

During the first month or two in the forest one is conscious of oppression and uneasiness. In contrast with the brightness of the open river the forest floor is wrapped in gloom relieved here and there by the bright dots of sunlight which filter through the roof above. The thickly packed trees average 100 feet in height, their upper branches merging into an almost solid roof. Here and there individual giants rise to 300 feet, their trunks 45 feet in circumference at ground level; a silk cotton tree of these dimensions was actually measured. The ground between the trunks is covered by slender saplings and cluttered with the debris of fallen and decaying vegetation. Visibility is about 20 yards, beyond which stealthy movement is difficult to detect. Here and there a pimpler palm rises, its bole well protected by long slender poisonous needles arranged in clusters of seven at regular intervals; or the friendly tauri, its giant fronds spreading in graceful curves. Everywhere there is creeper twining everything in its path in a relentless grip. It swarms up the tree trunks and spreads outward through the roof above or hangs in festoons, tying each tree firmly to its neighbors so that the whole roof is one tangled mass.

The forest consists of many different kinds of trees in haphazard arrangement, but areas where one or two kinds are in preponderance are sometimes met. Thus Wonatobo is surrounded by mora forest almost to the exclusion of all else; and at the source of the Oronoque the pimpler palm is everywhere. The mora is a magnificent tree standing firmly on a base of solid buttresses which radiate like veins from the trunk 10 feet above ground level, spreading outward and decreasing in height, twisting in freakish folds until they disappear below ground level 10 feet from the bole. Mora is much prized for boat building and is reputed to be superior to English oak. Another truly magnificent tree is the cedar, the reddish-colored wood of which gives off a delightful odor. The yariola tree makes excellent ax handles and paddles. The trunk is not solid, but consists of many smaller trunks joined to each other at intervals, the whole sweeping aloft like a beautiful fluted cathedral column. The boles of some trees are rough, others smooth and slippery, while some are studded by enormous conical spikes for several feet above ground

level; some do not touch the ground at all but stand supported on a multipod of roots.

Creepers vary in size from the thickness of a man's thigh to that of a shoelace. Some are coarse ribbons 4 inches wide and half an inch thick, their centers indescribably tuckered to look like a fairy staircase; others are large and soft like the warps of a ship. One freak 6 inches in diameter tied itself in a perfect thumb knot 20 feet above ground, then continued upward, to curl around its host, the tree. One kind of creeper contains water, and if a length is cut and inverted over the mouth, it gushes out, giving a satisfying drink. In its struggle to reach the upper air and sunshine, the creeper often kills its host, the tree. The gaunt trunk remains standing connected to its fellows by a hundred ropes till a sudden squall of wind will bring it and many of the supporting neighbors crashing down in tangled confusion.

Amongst this riot of vegetation surprisingly little food edible by man is found. A wild red plum and a green bean appear in isolated places. The plum has a tart sickly taste, and the pod of the bean is very sweet. Neither can be recommended. The Brazil nut is unfortunately rare, but each tree yields an immense number of nuts. Monkeys pick the ripe pods, the size of small melons, and hammer them against the trunk till they break, when there is a wild scramble for the falling contents. A few of the palms have edible cabbages, rather like celery and quite pleasant to eat. Only one wild cocoa tree was found. The soil is said to be poor, but if a clearing is made, pineapples, bananas, tomatoes, and the starchy vegetables peculiar to the colony can be readily grown. There are very few flowers on the forest floor, but many of tree and creeper can be seen from the air in the forest roof.

The results accomplished in the first season's work were disappointing; base camp was established at King Frederick William Falls and the trijunction party started upriver from there at the end of October. The Dutch and Brazilian sections were met at the source of the Kutari at the end of the year. The source of the Courantyne was decided upon and an astronomical fix obtained. A large concrete pillar was constructed there and suitably engraved. The Dutch then departed to the east along their boundary, while the British began to work westward. In the meantime the second British party explored the Aramatau, marked its source, and started to trace the boundary eastward. Some idea of traveling speeds can be obtained from the progress of this party: Aramatau Camp was left on January 16, but the boundary was not reached until April 14. The Oronoque was also explored and surveyed to within 10 miles of its source in preparation for the following

season. Field work stopped in May, when survey parties returned to Georgetown for 10 weeks, leaving fresh boats' crews to provision all camps during the high water. Base camp was moved to Oronoque. During the recess the British and Dutch sections placed pillars at the mouth of the Courantyne to mark the direction of the boundary through territorial waters. In August 1936 the survey parties again took the field, but with a very different outlook. All ration depots were well stocked; Indian and Negro labor was more plentiful and better understood by the officers; and much of the upper river was cleared for canoe communication. The international watershed was located at the source of the Oronoque by the beginning of September, and an astronomical pillar erected. The boundary was traced eastward, and rapid progress made through a country of small lumpy hills 200 to 300 feet high, separated from one another by creeks and swamps.

Bush survey has a rough-and-ready technique of its own. A visibility of 20 yards, often less, is not conducive to rapid topography, and forcing a passage through the tangled undergrowth is so slow and fatiguing that the extent of the day's excursion is very limited. Nevertheless, it is surprising what good results can be obtained with care and a simple routine. The boundary was to be marked by buried stone on the international watershed at not less than 5-mile intervals, the position of such marks to be indicated by a small concrete pillar. Every fifth mark or 25 to 30 miles of boundary was to be fixed in position by astronomical observations and the whole connected by an instrumental traverse to the order of 1/250. In addition it was the practice of the British section to map the topography for 1 to 1½ miles on either side of the watershed, but during the last season this was discontinued.

The biggest problem was to find the boundary. Running water was plentiful, but to establish whether it was British or Brazilian without tracing its course for some miles was impossible. The creek heads of each country were twisted and contorted into a maze of steep little hills, saddles, and swamps, and every hill was, of course, a watershed. A creek would often wind its way in a general southerly direction for a mile or more, only to turn and prove itself to be British. One well-remembered creek actually split in two, the main branch flowing north to the Atlantic 400 miles away, while a smaller branch bubbled under some stones and commenced its 2,000-mile journey to Para at the Amazon's mouth. In desperation the boundary was placed up the center of its bed.

Boundary location was done by Indians, and it was a very arduous task, as it entailed cutting through virgin bush from morning to night, finding creek heads and tracing the water till it declared its

nationality by joining a larger creek which was already known, or by maintaining one direction for so long as to preclude the possibility of its turning back. A small party of four Indians equipped with compasses, and fondly referred to as the Advance Guard Cavalry, kept ahead of the boundary cut doing this work. They never stuck it for long and usually became badly infected by bush yaws and sores. It was their job to mark saddles on the international watershed, and connect their marks by a sirrahee or line just cut sufficiently to allow passage.

The Indian has one great failing. He has no idea of direction or, if he has, is quite incapable of explaining his wanderings or of making the simplest of diagrams to illustrate them. Time and again they would report that they had discovered a big creek ahead. When asked where they invariably answered, "Right away back," and usually pointed straight above their heads. Comparisons of size were conveyed entirely by inflexion of the voice: Thus a "big" hill was not uncommon; but a "BIG" hill meant something quite remarkable.

The boundary locaters' sirrahee was traversed by rope and sound for planimetry, and by aneroid barometer for height. Next came boundary cutters, who cleared the line sufficiently for the carriers and instrumental traverse. A day's work for a line clearer was 250 meters, and it was not easy. The boundary traverse was made with a 3-inch vernier theodolite set up on magnetic north at every second station. Distances were obtained by stadia, and heights were carried forward by vertical angles.

In the meantime the two topographical parties worked on either flank, running a chain of rope and sound, and aneroid traverses with their apexes on the boundary and bases parallel thereto. The technique of rope and sound is simple but effective. The rope is one-third of 100 meters, minus what it is expected to stretch, plus an allowance for not being laid in one straight line. The party is preceded by two cutters with a compass, who cut a sirrahee on an ordered bearing. Two men lay the rope down the requisite number of times, then the front man commences to sing. A compass bearing is taken on this sound from the last station and booked, together with the aneroid reading. The station is numbered and the party moves on. The traverse is plotted as the party moves along, streams and hill features being rapidly sketched by intelligent guessing. The Indian took well to such work, although he found the compass difficult to master.

The instrumental traverse was computed on magnetic north as the work progressed, and finally adjusted between the astronomical positions. The topographical traverses were plotted on scale 1/50,000,

fitted to one another, and finally to the adjusted boundary. The results were very encouraging. The finished boundary cut was used as a line of communication for the carriers. As this increased in length, another creek farther to the east would be explored and opened up from its lower end, and a depot of rations placed as near the boundary as possible. When this was found by the locaters, the old line of communication was broken and the new one used.

The astronomical stations offered a welcome rest from energetic traversing. Moreover the big clearing necessary for a glimpse of the sky permitted kit, bedding, instruments, and books to be dried in the sun. Observations were made by a 3½-inch Tavistock theodolite for exmeridian longitudes and circummeridian latitudes. The criterion was a probable error of about 0.^{s}02 of time and 0.″5 of arc respectively from means of 18 to 24 pairs of stars. Observations for azimuth were also taken.

Over 85 miles of boundary were surveyed and marked eastward from the source of the Oronoque during the season 1936–37. In the meantime the Brazilians progressed westward from Aramatau source. At the beginning of the following season the cuts were joined and the British struck westward from Oronoque source toward the headwaters of the Essequibo. Next season ought to see the field work completed, and the surrender of this fascinating but rather trying part of the world once more to nature.

The temperature on the forest floor has surprisingly small diurnal or annual variations. Midday temperatures are 88° to 90° F., midnight 82° to 84° F., with a 2° variation between midsummer and midwinter values. The humidity is very high, occasionally reaching saturation point, when small gray clouds of vapor form and drift between the trunks. This high humidity is one of the most unpleasant factors of bush life. To perspire gives no relief; clothes, bedding, and food are perpetually damp, and books fall to pieces after a few months. Unprotected metal corrodes overnight, and leather and glass grow whiskers of mold at an alarming rate.

Photography is beset with difficulties, and disappointments must be expected. The shutter mechanism and diaphragm of a camera corrode rapidly in the damp atmosphere, and finally cease to function. All glass is attacked by a black fungus which spreads and engraves its surface in blotches and spidery lines. On fine days intense sunlight filtering through the forest roof produces a brilliant dapple of dazzling contrast to the gloom of the forest floor. For this reason the best results are obtained by long exposures in slightly overcast weather. These are made possible by the absence of breeze on the forest floor.

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Photographic films and plates keep as long as they are stored in an airtight canister and their seals are unbroken. Once they are opened they deteriorate rapidly, and if not developed soon after exposure the emulsion, celluloid, and paper backing become a limp, sticky mass. Except near the boundary where the springs are clear and cold, it is difficult to obtain water clean enough and at a temperature below 75° to 80° F. for development. At this temperature the process is difficult to control, and even an acid hardening bath will not eliminate reticulation and frilling. It is also almost impossible to wash negatives adequately and quite impossible to dry them. Finally, when packed away under double seals they form an excellent medium for the growth of fungus.



1. KAITEUR FALLS.



2. KING FREDERICK WILLIAM FALLS.



1. BATEAU ASCENDING THE FALLS.



2. THE AIRPLANE AT WONATOBO.



1. BOUNDARY PILLAR.



2. BOUNDARY MARK.



1. A BOUNDARY CUT.



2. A FOREST CREEK.

THE SEA BIRD AS AN INDIVIDUAL: RESULTS OF RINGING EXPERIMENTS[1]

By R. M. Lockley

Skokholm Island, Pembrokeshire

We are accustomed to think of the sea bird plurally. We think and speak of a crowd of sea birds, or a flock of sea birds, or a host, a raft, a bunch, and so on through the list of appropriate or inappropriate nouns of assemblage. This use of vague and general terms is forced on us by the habits of sea birds, the majority of which spend half their lives, the winter half, on the sea at a distance from us, and the other half of their lives, the summer half, on lonely shores and remote islands not commonly visited by man. For this reason man has not been able to give much consideration to the idea of the sea bird as an individual. Nor is it easy to see how we may make close enough contact with the gull, the auk, and the petrel at sea to recognize and study individuals. It remains for us to study them in their terrestrial summer homes, and there they are generally packed together so closely, nesting in scores, hundreds, and even thousands, that at first glance we are quite bewildered by this apparently promiscuous communal home life, and we may wonder if they have individual existences at all.

I happen to have lived long enough on an otherwise deserted island to have been able to penetrate beneath this first impression. I now no longer think of sea birds vaguely, collectively. You have only to mention gannets, shearwaters, puffins, razorbills, or storm petrels, and I am immediately remembering certain individuals of these species with whom I am acquainted, and wondering how they are faring at sea at this moment and whether they will turn up for inspection on the island next spring. Such an individual, for instance, as the Manx shearwater that flew home from Venice, or the razorbill inhabiting a certain crevice on the island year after year.

But I must not anticipate. Skokholm Island lies a few miles off the coast of Pembrokeshire. It is rock-bound, about 240 acres in extent, and has only two houses on it, a lighthouse at the most westerly

[1] Address given at the Weekly Evening Meeting, Royal Institution of Great Britain, Friday, November 18, 1938. Reprinted by permission from Proceedings of the Royal Institution, vol. 30, pt. 3, 1938.

point, which is a mile from my own house on the east side of the island. There is good soil above the old red sandstone rock of which the visible cliffs are composed.

I had a great deal to do when I first landed on the island 10 years ago, for the cottage was in ruins, but I am not going into that aspect of my island life tonight. Suffice it to say that I was attracted to the island in the first place by its great wealth of sea bird life. Later, as opportunity afforded, I began to look into the individual lives of these birds.

The first essential in such a study, since individual sea birds of one species are more exactly alike than peas in a pod, was some method of marking. Color marking of plumage, which we at first tried, was unreliable—the birds soon preened off the most tenacious pigment when they got back to the sea. Clipping portions of certain feathers was open to objection as mutilating the plumage, and anyway these marks were lost in the annual molt. Then I heard of Mr. Witherby's scheme for marking birds with numbered leg rings. This scheme, which is now taken over by the British Trust for Ornithology and is housed in the British Museum of Natural History, is not as well known as it deserves to be, for it has certainly revolutionized bird study.

There are seven sizes of rings to suit all species of British birds from a wren to an eagle. Each ring has a serial number and the inscription "Inform British Museum Natural History, London," so that those who capture alive or find dead a bird with such a ring will know what to do in the interests of scientific bird study. I may add there are similar ringing schemes in operation today in many other countries.

All birds are not easily caught and so do not lend themselves to ringing, but some sea birds do. I started with the Manx shearwater, *Puffinus puffinus puffinus* (Brunn), a bird whose habits were at that time very little known (1, 2).[2] It is rather a helpless bird on land and is easily killed by predatory gulls and hawks. For that reason it spends the day at sea or in the depth of a rabbit burrow on the island, only returning from sea or coming out of its nesting hole when the night is sufficiently dark to make it difficult for the predators to see it. I say sufficiently because I soon found that if the moon were visible on any night the shearwater refused to appear, even though earlier in the evening, just before sunset, it had assembled ready to land, gathering in great flocks on the sea near the island. But on a dark night the shearwaters arrive in thousands, making a great uproar with their unearthly screams, and for the few hours of summer night carrying on the business of nesting. There are probably 10,000 pairs breeding on Skokholm.

[2] Numbers in parentheses refer to list at end of article.

The shearwater nests in a hole in the ground, sometimes deep in a rabbit hole, but it will also excavate a hole for itself in soft ground. A small colony nested in shallow burrows within a few yards of my back door. So it was not difficult for me to trace with a stick the winding of each burrow to the nesting recess at the end, and to cut out a turf immediately above the nest and then to use that turf as a convenient inspection lid. I wish I could tell you how much pleasure my wife and I got out of this acquaintance with the individual bird. In successive seasons individuals returning to the same burrows became almost tame and quite used to handling. Of course we had to lift them out of the nest very frequently in order to note the ring number by which we identified them as individuals.

By degrees we were able to work out something of the Manx shearwater's life history. The burrow would be inhabited as early in the year as February, the paired birds meeting each dark night as if they were determined to make sure of their nesting territory in good time for another season, although laying does not take place until late April and May. Ringing has since told us that the old breeders always arrive first.

There seems to be a shortage of desirable burrows. Ringing told us that, in the absence of the legitimate pair, their burrow might be seized by another home-hunting couple. We ringed these wandering couples, of course, and found that they were moving from hole to hole like the newly married in search of the ideal home. This spring hunting was not without its comedies. We would surprise lovesick couples trying to convince each other with much crooning—for that is not an unfair description of the bird's powers of conversation—that the shelter of an old box, a plank or some other inadequate recess, was the real thing. But the light of morning would prove that these places were not dark enough and the lovers would fly out to sea before the predatory gulls and hawks discovered them. Sometimes, too, we would find a bird of one pair, which we had registered in our books as an established married couple, sitting in its burrow with a strange bird, an unringed bird, or at least a bird recently ringed as a newcomer to the colony. It was easy to interpret this new bird as an interloper enterprisingly on the lookout for a ready-made home, if not also a ready-made mate. This promiscuity was frequent up to the time the egg was laid. We found that after that date the pair which was properly registered, the pair which had done the donkey work, if I may use the term, the digging and enlarging and the nest lining, and performed the evening concert of crooning, this pair settled down to incubate. The occasional visitor now seldom or never intruded upon the domestic scene. Sexes are indistinguishable in the field, but in some cases we knew the female

by finding her on a new-laid egg. Only one egg is laid and incubation is equally shared. Thus, for instance, the male would spend 2, 3, or 4 days on the egg without quitting the burrow, then the female would take over. On dark nights the bird at sea would return and converse with the sitting bird for an hour or two, but would not necessarily relieve it. Nor could we get any evidence that it fed its sitting mate. We came to the conclusion that the sitting bird stuck to the egg as long as hunger permitted, or as long as it could retain possession of the egg against its mate's determination to brood it. This at least appears to be the explanation of the irregular shifts or watches by one or other of the pair on the egg on dark nights.

On moonlit nights, however, this ardor to incubate was cooled by what we presume must be the bird's fear of being seen and killed by the predatory gulls and hawks which frequent the island, as already mentioned. So when a period of moonlit nights intervened the bird at sea never visited the bird on the nest at all. Thus for 5, 6, 7, and more rarely up to 10, and once 12 nights and days, when the moon happened to be near or at the full and the skies cloud-free, the sitting bird remained brooding but starving at the nest. We even weighed some of these starving birds and proved an average loss of a very small fraction of an ounce every 24 hours. Starving is really the wrong word, though at the time it seemed appropriate in our view. Now we have learned that a sea bird can easily endure long fasts and no doubt this fact will help us to understand how the sea bird survives long storms at sea, when the weather conditions are such that feeding may be impossible and the bird's energies may be entirely directed to fighting the storm.

The incubation period of the shearwater we found to be a record for a British breeding bird—50 to 54 days. One parent remained in the burrow by day to brood the downy chick for the first week of its existence, but afterward it was only visited by night. When the moon was bright at night, the same thing happened as during incubation—the burrow was not visited at all. The young chick thus early had its first lesson in fasting. However, it was fat from the day of its birth, and showed no perceptible sign of going back during the occasional enforced fasts, in fact it seemed simply to sleep and, so to speak, consolidate the position already gained. At any rate this program of cramming interspersed with an occasional fast results in the chick becoming enormously fat by the time it is 60 days old. To our surprise we now found that the parents deserted the chick. They had spent 60 days busily gathering fish for it and many nights feeding it from the supply of semidigested food stored in the parental crop. Now suddenly and completely they gave up all this, and stopped visiting the burrow, and probably the island,

since the burrow, after all, is the only point on the island that has ever attracted them. They went off to sea and certainly would not appear on the island again until the following spring. Probably, in their winter quarters at sea they would soon be plunged deep in their molt, which takes place in the autumn. We can surmise, if we like, that the physiological state immediately preceding the molt has something to do with this, to us, rather unnatural desertion of the tender nestling.

And yet if it seems unnatural, it is at least not improvident. At this age the chick is so fat that it could scarcely waddle to the sea. If it did so and plunged over the cliffs it would drop like a pound of butter and go to pieces on the rocks below.

The chick has never been out of its burrow yet. Since its parents vanished, the matchsticks which we have placed at the entrance to the burrow have remained upright. (We used matchsticks a great deal in these experiments to enable us to prove whether a burrow had been visited by night, for of course it was impossible for us to remain watching every night personally.) After about 6 days the fledgling is beginning to thin down, and probably feeling hungry and cramped it now comes out of its burrow for an hour or two each dark night. It not only proves this exit by pushing over our matchsticks, but it leaves additional evidence in a trail of the natural down which it has lately molted. These deserted chicks, sitting outside their homes at night, are a regular, if rather pathetic, feature of the island on dark nights in August and September. In the open air they can try their wings at last. They flap their wings a great deal, but do not move from near the entrance to the burrow, into which they retire before dawn. After a week of this fasting and a week of this combined fasting and exercising, the fledgling is fully feathered and has very little down visible. It takes off for the sea at night, blundering along on all fours, using wings and legs and beak to scramble over rough ground, for it cannot fly yet. When it reaches the cliffs, over it goes and flaps down on a long plane to avoid the rocks below.

Once in the sea the young bird is safe. We have taken shearwaters at this stage and put them in the sea by day. How thirsty they are—I wonder if thirst may not be for them an important factor in drawing them to the sea, the sound of which they must hear before they leave the nest? At any rate their first action is to drink, then to wash, then suddenly they discover that they can dive. They half open their wings so that the quills remain partly spread, like a half-opened fan, and with these strong paddles they swim under water with the agility of penguins. They come up for air, and dive again, and so gradually work off to sea, making haste to leave behind the

land, of which they have perhaps unpleasant memories of hunger and thirst. When a gull has swooped at a young shearwater so released by us, the shearwater has simply dived deep and swum away under water.

Although we have ringed these young birds, for the time being we have lost them as individuals. They have vanished into the ocean (3). However, by ringing hundreds of them we are now beginning to get some returns at sea of both adults and young. One youngster ringed on Skokholm on September 1 got blown by a gale into the Rhondda Valley 9 days later. That, of course, was an obvious mishap. Another young shearwater took only 3 days to get to the north of France, at St. Valery. We look forward to more recoveries from large numbers recently ringed, and we are expecting that the young birds will be proved to join up with the adults, which wander as far south as the Bay of Biscay, and there a good number of our breeding birds have been recovered (4). They are reported from various sources. French and Spanish fishermen shoot or capture alive many kinds of sea birds. These men open the birds' stomachs to find out what they have been feeding on. If the fishermen find edible fish therein they set their nets in the place where the birds were feeding. Perhaps the most curious recovery was that of a ring found in the stomach of an angler fish caught from the pier at Douarnenez, in Brittany. Now the angler fish weighed 40 pounds, so it was large enough to swallow not only a shearwater, but even another fish which may have attacked the shearwater and bitten off its leg with the ring attached. I say this because when ringing shearwaters on the island at night we have sometimes found birds with mutilated feet, the webs between the toes missing, and even a leg severed at some point on the tarsus. An angler fish feeds normally at the bottom of the sea, but it may have swallowed a surface-swimming fish which had previously snapped the leg off the shearwater. This is mere speculation, of course.

Curiously enough, ringed shearwaters have been reported to us from the Spanish coast as late as the month of May, when you would expect them to be back breeding on Skokholm. But these appear to be young birds 1 and possibly 2 years old, which are not quite ready to breed yet. Certainly our old ringed birds are always back in their burrows in February and March. But no shearwaters ringed as nestlings have been recovered on Skokholm so far earlier than the middle of July of the year following that of their birth. This suggests that in the second summer these youngsters are only visiting the island in order to familiarize themselves with the breeding ground for future years. In confirmation of this we have found young pairs with quite undeveloped breeding organs indulging in

what might be described as "calf" courtship in burrows at or after midsummer. Of course no egg was laid. But we need more ringing records before we can speak positively as to this adolescent period.

By means of ringing, however, we have, as I have shown, at least traced the shearwater to its winter haunt as far south as the Bay of Biscay. And we have found that the old breeding birds return faithfully to their nesting burrows early in the spring. But do the same individuals pair for another season, for life? Ringing says yes. The breeding bird has built up an association of memories—I hardly like to call them visual memories in view of the fact that some of the most important events take place in the pitch blackness of the burrow—an association of memories which lead it back to the same burrow. It must lose contact with its mate at times at sea in winter, possibly altogether—I do not know. But at least the nest is the focal point, the well-remembered place of meeting, and, allowing for frequent gaps caused by death, we have proved by means of ringing that the shearwater pairs for life.

You may ask what about the young bird? Does it, too, in succeeding years return to the nesting burrows in one of which it was reared? So far we have not recovered a young bird in the immediate neighborhood of its birthplace. But it is obvious that in order to keep up the numerical strength of the species a great many young birds must return to breed on the island. It is interesting to speculate as to whether they are guided to the island in the spring by the movements of the adult shearwaters or by memories of fledging days. Possibly both these factors operate, and the young bird gradually builds a fresh association of memories during the preliminary visits to the island which I have already mentioned. It discovers an empty crevice or hole one night and finds a mate, or more properly I should say a sweetheart, and plays at housekeeping. Next year it will return to this spot, search for or dig a more suitable hole, and start a home in earnest.

To return to more definite information. At present we have adult shearwaters under observation which have bred with us for 3, 4, and 5 years running, and there are two individuals which have bred 7 years running. Assuming that the shearwater does not breed until nearly 2 years old, we thus have individuals 5, 6, 7, and 9 years old. So that in time we may well be able to work out the average duration of life of this species.

This ringing study of the Manx shearwater, if it has enabled us to discover something of the bird's life history, has also revealed our lack of knowledge of many aspects of its life; for instance, its ability to find without error its own burrow among thousands of other burrows crowded close together, as they are in some parts of the

island. We can take it that the shearwater has an eye well adapted for nocturnal work, but I do not think that the power of its eye can account entirely for the ease with which it picks out the entrance to its burrow in a crowded warren on a dark night, and the ease with which, having alighted beside the entrance, it finds its way in the dark labyrinth underground to its particular nesting recess. There is some other power there, probably not unconnected with its wonderful sense of orientation.

I have seen sea birds such as puffins, razorbills, and shearwaters flying confidently through thick mist in the direction of their breeding grounds when I only knew that direction by a study of the compass. How is this done? How, indeed, does another shearwater, the great shearwater which winters in the North Atlantic during our summer, find its way back to its breeding ground in the Tristan da Cunha group of islands, a group which is but a needle in the haystack of the South Atlantic Ocean? If we knew the answer, we should know the mechanism of the bird's power of orientation. One worker, Dr. Riviere, has called this power "a sense of geographical position" (5). Dr. Riviere was working with homing pigeons flying over land or within sight of land. But the sea bird may be out of sight of land for days on end. Moreover, it does not usually fly high like a pigeon; more usually it skims the tops of the waves, so that its horizon must be very limited.

We have conducted some experiments with ringed sea birds in an attempt to learn something more of this homing power (6). I cannot give tonight more than a short sketch of the more important results. An adult shearwater was taken from its egg on Skokholm and released at Start Point, in Devon, which is about 220 miles from the island by the sea route around Cornwall, or 125 miles overland as the crow flies. When released it flew low over the waves making for sea. It did not attempt to rise up and strike overland in a beeline for the island. Yet that bird was back on its egg at Skokholm within 10 hours, so that if it continued by the sea route it must have flown steadily at 22 miles per hour. Of course its speed by this sea route must have been much greater, since a shearwater normally does not travel in a straight line but has a curved deviating flight, and probably it paused to drink if not to feed.

Two birds released at Frensham Pond, Surrey, performed a similar feat and were back at their nests the following night, but in this case, before reaching the sea after release, these birds had to cross 40 miles of land. But land masses interposed between shearwaters and the sea do not seem to disturb the homing faculty. Shearwaters released at Birmingham, Evesham, and Manchester, as well as at Limerick, in Eire, have safely homed to Skokholm, though not with

the rapidity of the Start Point and Frensham releases. Other birds released in the Firth of Forth and as far north as the Faeroe Islands, and as far south as France and North Spain, have also got back to their nests on Skokholm in varying times. All these homing experiments were within the known range of the species. We needed to go farther afield and see what would happen to birds released outside that range. The farthest distance by sea for which we could easily arrange without transport hardships for the birds—for we had to be sure the birds were in good condition for a long flight—was Venice, in Italy, approximately 3,700 miles from Skokholm via the Adriatic and the Straits of Messina and Gibraltar. By courtesy of Imperial Airways, two shearwaters from separate nests were sent to Venice, the distance by air being a little under 1,000 miles. As far as I know the Manx shearwater does not enter the Mediterranean and therefore is not found in the Adriatic. Certainly ringing has so far proved that our Skokholm birds in their winter wanderings do not go beyond the Bay of Biscay. One of these two shearwaters is an individual of some interest to us, for it has returned to its burrow on Skokholm for five consecutive summers. It had already returned safely from Frensham. Now it returned from Venice in 14 days. It is impossible to say whether it homed over the Alps in a beeline for Skokholm, or whether it found its way out through the Straits of Gibraltar, or whether it crossed the backbone of Italy and then over the Pyrenees to the Bay of Biscay. In any case it was a wonderful performance. You can imagine our anxiety as night after night we waited at Skokholm, and I must say that I did not expect it to return. Meanwhile its mate had carried on very nobly, after a week hatching the egg, and then carefully tending the chick alone. I can assure you that there was a great to-do in the burrow on the fourteenth night when I went out on my regular inspection round and discovered the parents together with the chick. Even before I opened the nest I could hear their crooning conversation. I have no idea what this may have been about, but an imaginative person might have concluded that there was expostulation as well as congratulation going on, and even the chick was chiming in with an odd squeak here and there.

The other shearwater may have returned from Venice in that summer, but we did not catch it until the next spring, when it was back at its usual nest.

Similar experiments with sea birds have been made by workers in America (7) and with similar results. Yet while these experiments have proved a remarkable homing ability, we still have nothing but theories to explain it, and the physiological mechanism remains obscure.

There is much more that might be said of that interesting and unusual individual the shearwater, but I must pass on to a brief mention of our work with individuals of other species of sea birds—the storm petrel, *Hydrobates pelagicus* (L.), for instance, which breeds in numbers in the rock crevices and old farm walls of Skokholm. In a similar study (8) of individuals it has shown a life history not unlike that of its cousin the shearwater: nocturnal on land—a long incubation period of 38 to 40 days—and an average fledging period of 61 days. The chick is deserted in the end, and flies off to the sea on its own when sufficiently thinned down from its over-fat nestling stage. The storm petrel is more nervous and difficult to observe than many sea birds, but we have individuals on our books that have been breeding in the same crevice on the island for 4 years.

So, too, with the puffin, *Fratercula arctica grabæ* (Brehm). Our ringing study of this bird enabled us to discover several new facts (9): an incubation period of 40 days and fledging period of 49 days; also that this bird, too, is deserted by its parents, although other members of the auk family to which it belongs, the razorbill and the guillemot, feed and accompany their chicks at sea when these leave the rocks where they were hatched. The puffin follows the petrel family in deserting its single chick, but this desertion, as with the petrel family, is a wise provision. The guillemot and razorbill chicks, hatched on the precipitous ledges of the cliffs, can and do easily jump or flutter down to the sea and their waiting parents. When they take off like this they are fully feathered but only half-grown, and are so small and light that even if they hit the rocks a hundred feet below on rare occasions, they generally bounce off unhurt, and scramble off to the safety of the sea. They leave in broad daylight, when they may best see their parents on the sea below. But the puffin is often reared in burrows some distance from the edge of the cliffs, and so has a long walk to get to that edge, and during that walk it would be exposed to the attacks of gulls and hawks. Moreover, it is full-grown and very fat when it is deserted by its parents. It certainly needs a fast of a week or so to make it light enough to take off without fear of crashing on the rocks below the cliffs. So the young puffin solves these problems (the problem of its excessive weight, and the problem of the predatory gull) by starving for some days before selecting a dark night for its lonely and unseen, but momentous, stroll to the cliff edge, where it takes the plunge to that friendly element, the sea.

One of the most attractive birds to study has been the razorbill, *Alca torda* (L.). It is a handsome looking bird and nests in the pleasant environment of the rocky slopes of the island shore, where

wild flowers form a natural garden of great beauty about the boulders and crevices under and in which the razorbill lays its single egg. But the individual razorbill has not been the easiest bird to study, for it has the annoying habit of wearing out its ring on the sharp sandstone rocks of Skokholm, owing to its method of walking with its tarsus close to the ground. For this reason practically all our earlier records of individuals have been lost, the numbers on the rings having been obliterated in a single year, and in 2 years the rings were worn through and dropped off. Stronger rings are now being made, and by giving the birds a new ring every year in place of the old, we are keeping track of some promising individuals who have returned to the same crevice year after year. In the winter individual razorbills have been recovered as far north as Norway and as far south as the Gulf of Genoa, Italy.

The guillemot, *Uria aalge albionis* (With.), breeds on less accessible rock ledges, but we are keeping account of such individuals as we have been able to capture here, and we try to ring all the young guillemots just before they fly.

The gannet, *Sula bassana* (L.), does not actually breed on Skokholm but on the neighboring islet of Grassholm, which is the only site of this species in England and Wales, and one of the most important of the 20 colonies known to exist in the world. On Grassholm there are today approximately 6,000 pairs of gannets. Since 1933 we have ringed large numbers of gannets there in most summers. An analysis of the returns from this marking suggests a very interesting migration. In their first winter the young gannets go a long way south, several individual young birds from Grassholm having been recovered off the coast of West Africa in latitude 20°N. Gannets in their second and third years, however, do not seem to travel so far south. At least we have no records of Grassholm gannets of this age farther south than the Straits of Gibraltar and the coast of Algeria, at Oran. While older birds, gannets in and past their fourth year, remain nearer home, no ringed gannets of this age have been recovered farther south than the most northerly corner of the coast of Portugal.

While it is never safe to dogmatize from these records, we can suggest that, as the gannet reaches a mature state of plumage and breeding condition in and after its fourth year, it may be disinclined to wander far from its breeding site. This is to some extent confirmed by the fact that adult gannets assemble at Grassholm as early as February, and they do not leave until the end of October or the beginning of November.

We have on Grassholm at the moment some individual adult gannets which have nested there 3 and 4 years in succession. If the gannet does not breed until 4 years old, these individuals must be 7 and 8

years old. However, we may have to wait some time to get longevity records of the gannets—if we are to believe one writer (10) who, from an examination of the ovaries of a shot gannet, considered that it had laid 150 eggs. A gannet, of course, only lays one egg a year, so this bird, if we add the years of its adolescence to this total, would be well over 150 years old! However, in this instance the circumstantial evidence was not conclusive.

If we can only continue our ringing work in the years ahead we may be able to answer definitely another much-disputed question, that is, the age of the gannet when it first breeds. Ringing should eventually prove this, if we are lucky enough to catch an adult at Grassholm which was marked by us as a nestling there.

I have spoken of ringing large numbers, even thousands, of sea birds, and it may be wondered how it is possible for one person to do this and keep account of so many individual birds from year to year. It certainly would be difficult for one person to do this. When I began this study of the individual sea bird I had only my wife's help, and very valuable this was. But we should scarcely have been able to carry on this work as well as our normal duties had not we received some encouragement from outside, an encouragement which we were most grateful to have. In the last few years more students have come along, until a voluntary organization has grown under the name of Skokholm Bird Observatory. It is now so organized as to permit us to endeavor to ring every breeding bird on Skokholm, from a rock pipit to a gull, and to the gannets of Grassholm. We also catch many migratory birds which use the island as a temporary resting place. For instance, we ringed this year over 6,000 birds of 61 species. This is a figure comparable with figures achieved by subsidized observatories in foreign countries. In Germany and Italy and the United States ornithological work of this nature is recognized officially as having an educational and scientific value, and it is blessed with the practical support of the government concerned. Here in Britain ornithology outside of museums depends entirely on voluntary support. So that the running of an observatory on a remote island is not without its anxieties in more than one direction. Rings at three farthings each add up to a considerable figure in 1 year; there is a large amount of clerical work in the recording and card indexing of thousands of individual ringed birds, and there is even the danger that some of the vast amount of information gained will be buried for lack of time and volunteers to sort, collate, and publish it.

Nevertheless, this voluntary organization is being carried on for the present and is about to issue its third modest annual report (11). It is also proposed to publish in due course further papers of a scien-

tific nature placing on record the results of bird marking and other investigations being carried out at Skokholm. Some small evidence of this work you will have seen in the graphs, maps, and other material exhibited in the library this evening.

Finally, it may be suggested that catching and handling birds must disturb them unduly. On the contrary, by gentle handling many birds have become so used to us that they are almost tame; as tame, in fact, as wild animals become in nature reserves where they have learned that no harm will come to them from human beings. Indeed, if the birds did not become reasonably tame it would be impossible to study them individually. This way of studying birds by ringing them is a good deal better than the old way of studying them by means of the gun and the collecting box. Ringing establishes a new kind of contact, a sort of friendly conspiracy with the living bird.

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BIRDS AND THE WIND[1]

By Neil T. McMillan

Captain, Eastern Air Lines

[With 3 plates]

Wind is the major influence in the life of a bird. It is a strong factor in his daily activities. His range and habits are controlled by the use he can make of the wind. During migration it is wind that sets the routes and schedules and is the primary cause of delays and accidents. In reality, it is the air that goes places and the birds go with it. Unless forced, a bird will not fly any great distance. Whenever possible, he rides the wind.

These are not statements of established fact made by an accomplished ornithologist but the personal beliefs of an aviator who freely admits that he has a better knowledge of wind that he has of the birds. Because his own work is controlled by wind, he is certain to regard both it and the bird in a different way than a bird student who spends the major part of his time at the bottom of the great ocean of air. Neither view is likely to be wholly correct nor is it likely to be entirely wrong. Because his beliefs may have some value, the writer welcomes this opportunity to tell of them.

To a bird on the wing, the wind is a vehicle or means of transportation—not a propelling agent. Through countless generations of living on the surface of the globe where two elements—air and land or air and water—are in collision, man came to associate wind with a pushing force that could vary in intensity, from a breeze that caressed his cheek to a tornado that hurled him to destruction. When he learned to fly, he found that as soon as he was free of the earth his old conception of the wind was wrong. What is true in aviation is true in ornithology. A bird is carried. He is never pushed or blown.

Although A. Landsborough Thomson and a few others have recognized it, there is much in the literature on birds to indicate that this essential truth has been missed. Such expressions as "flying in the teeth of a gale," "buffeted by high winds," and "blown far in-

[1] Reprinted by permission from Bird-Lore, vol. 40, No. 6, November–December 1938.

land," are frequent. Several ornithologists have predicated their explanations of the way in which birds maintain their directions on the false assumption that a flying bird can feel the pressure of the wind. At least one has used mathematics to determine how much lift a bird can get from winds of varying velocities when the wind cannot strike a bird in the air. One authority has made the extreme statement that "strong winds blowing in the direction in which the birds are traveling are bad, since they interfere seriously with balance, and disarrange feathers."

A flying bird, which is essentially a part of the wind, cannot be struck by it any more than a man can be struck by the automobile in which he is riding. To obtain a true picture it might be better if the word "wind" could be discarded and "air current," "air stream," or "air river" substituted. This nomenclature may make it easier to understand that anything suspended in air cannot feel its movement. A log floating in the water of a river has no pressure exerted upon it. There is no water piled up in front. There is no wake. Viewed from the shore the log may seem to move but it is the water that is moving. In relation to the water, the log is stationary. The same liquid surrounds it at all times.

A balloon in the air is like the log in water. Although it may move over the face of the earth at 50 miles an hour the flag on its halyards will hang in a dead calm. It is the air that is moving, not the balloon. A bird cannot float like a balloon but he can accomplish the same result at the point where his own air speed is sufficient to give him enough lift to balance gravity. He moves through the air while the air itself moves, just as a boat on a river moves through the water while the water moves. Like a boat, which will have the same pressure on the bow for any set speed in any direction, a bird will feel pressure on the forward part of his body in ratio to his own air speed whether he moves upwind, downwind, or crosswind.

Even if he rides a hurricane that is spinning at well over a hundred miles an hour, the bird will feel not an ounce more of pressure or have a single feather ruffled. So long as he stays aloft he will be in no danger from the wind but an attempted landing would be certain to result in disaster. The bird must ride out the storm or reach its calm "eye" before he can alight. As a possible explanation of the many instances of birds being found in the "eye" it might be of interest to note that the air of a hurricane spins inward and a bird riding the storm for any length of time must inevitably be carried to the center.

Only in collision can moving air exert pressure. That collision can occur with the earth and objects attached to it, or it can occur

when a moving air mass meets air moving in a different direction. Just as eddies and rip tides are visible evidence of opposing currents in water, so are many of our storms eloquent testimony of a battle of winds. A bird changing from one current to another is analagous to a man stepping from an escalator moving in one direction to another moving in the opposite. There is a distinct shock which is gone as soon as the change has been made. The bird, even though he may be flying slowly, is relatively fast for his size and makes the change quickly. Long dirigibles, slow for their size, have been literally sheared apart when straddling strong opposing currents. It is possible that birds receive painful wrenches under like conditions and endeavor to avoid them.

Horizontal flight requires the most frequent change on days when the currents are vertical. An ornithologist has made the guess that migrating birds fly high on clear warm days because they are using rising air to give them lift. It is the guess of the writer that they fly high for the same reason that he does, to escape those currents. Nature abhors a vacuum. Air rising from the surface must be replaced and on the days in question the replacement comes from aloft. A "thermal," whether it is a steady stream or a series of bubbles of hot air, resembles a fountain. The air goes up, but it also comes down. For every updraft there are compensating downdrafts and flight through them is a continual jarring and bumping.

The upper limit of these convection, or mixing, currents is usually marked by a layer of smoke and dust that has been carried aloft. Above it there will be a horizontal current of air into which the thermals cannot rise and where smooth flight can be maintained. The highest elevation at which the writer has seen birds was at 7,200 feet, just above the dust level near Port Arthur, Tex., where he passed a flock of 20 or more in light brown plumage. At an air speed of 160 miles an hour he was upon them and had scattered and passed them before they could be identified. The significant feature of the occurrence is that the birds were going with a 22-mile-an-hour wind out of the west-southwest.

What were the birds? Whence had they come and where were they going? The writer would very much like to know, just as he would also like to know how, in April of this year, a lone goose happened to be on top of a solid overcast riding a 30-mile-an-hour east-southeast wind over southern Alabama. Snap judgment would say that the goose was lost and bewildered. But he may have known exactly what he was doing when he chose to ride a wind, above the clouds, that was totally different from that underneath. He may have known that wind never travels in a straight line, that a small arc of

it, like a section of the horizon, may appear to be straight but is in reality curved. If so, he knew that the wind he was riding would carry him to the Mississippi flyway, that it would shift to southeast before he reached the valley, then to south-southeast and south.

This is, of course, pure guesswork and may sound visionary, except that it is no more preposterous to grant the goose full knowledge of horizontal winds than to give definite knowledge of vertical winds to soaring birds. Obviously, a turkey buzzard gains altitude on a rising current of air. Using gravity for motive power, he noses down slightly in a remarkably flat glide and descends more slowly than the air is rising. When he has exhausted the lift of the ascending current or wishes to change position, the buzzard sharpens his descent and glides swiftly across the neighboring down-draft. Whether he gains or loses altitude in the long run will depend on the length of time he is in the opposing currents rather than on the strength of those currents. When using a thermal too small in diameter for him to turn in, the buzzard employs the same tactics. In the part of his spiral that is out of the current he moves rapidly. When he strikes the rising air he pulls up sharply, so sharply, in fact, that the end flight feathers of his wings open like the slots of a "foolproof" airplane to prevent a stall and loss of control. Watching a buzzard will give evidence that he has a knowledge of, and is using, moving air.

It is certain that, in the daily life of soaring birds, wind is a necessity. They must have rising air. Without it they are all but helpless. Their large, high-lift wings make them excellent sailplanes and exceedingly poor flyers. A kingbird can make life miserable for them. A difference in wings gives the advantage to the smaller bird.

It is the way in which he is designed that will govern how much or how little the bird can use the wind. Wing loading, or the ratio between wing area and weight; aspect ratio, or the relationship between length and breadth; camber, the thickness of the wings; dihedral, the angle between the wings; and the other problems that beset the airplane designer, must surely control the efficiency of the bird. If he can make but little use of the wind his range will be restricted. If he can remain aloft with only slight effort he will roam like the wind from one far corner of the globe to the other.

A quail takes off and climbs with the speed and steepness of a pursuit plane but he cannot long maintain the great amount of energy which this entails. He gains altitude rapidly and then glides, preferably downhill or downwind. This necessarily confines the quail to short flights and he does not wander far from his birthplace. His neighbor, the dove, climbs at a lesser angle and uses less energy. But

without a great amount of lift, the dove must fly rapidly to remain aloft. On his whistling wings he ranges farther than the quail but he falls far short of the yearly journeys of birds with more efficient wings, which use less energy and can maintain lift with less speed.

Apparently, this speed is, in many cases, surprisingly low. Watching herring gulls from the docks in New Orleans, the writer has seen them hover in light breezes which he estimated to be between 5 and 10 miles an hour. Beating their wings very slowly, the gulls matched the velocity of the wind with their own air speed and remained over one spot in relation to the earth without gaining or losing altitude. Even if the larger estimate of the wind's velocity is taken, the resulting figure of 10 miles an hour is far short of the 40-mile speed with which migrating gulls have been credited.

From personal observation on the airport of New Orleans, where the gulls flock when a stiff wind blows off Lake Pontchartrain, the writer believes that 40 miles an hour is too high for even the maximum speed of the gull. On two occasions when the airways weather station was reporting winds of 27 and 28 miles an hour, only a few of the gulls, when forced to take off, could make headway. These were the young in brown plumage. A few of the adults were able to match the wind but the majority were carried backward and dived to a landing. The maximum air speed of the gull, therefore, would seem not to exceed 30 miles an hour, and may be less. The anemometer is on the roof of a three-story building; none of the birds reached that height, but stayed low where friction was reducing the velocity of the wind.

The conclusion the writer draws from these observations is that when the migrating gull was timed at 40 miles an hour, he was riding a 30-mile wind. It may be argued, of course, that the gull was flying 30 miles an hour on a 10-mile wind, but that seems contrary to efficiency. Under the dynamic law that pressure increases as the square of the velocity, it would take something like nine times the energy to propel the gull at 30 miles an hour that it does at 10. Even if it is granted that a bird can change both his angle of attack and angle of incidence—the angle at which his body and wings strike the air and the angle at which his wings are set to his body—the energy necessary to fly at full speed must be out of proportion to the gain in velocity. To the writer it seems illogical to suppose that a bird, unless forced, frightened, or playful, will fly at anything but the speed at which he uses the least energy. A man can run, but he usually walks. The writer prefers, therefore, to believe that the gull, when timed, moved through the air a distance of not more than 10 miles while the air itself moved 30 or more and that the gull rode the wind as surely as a man rides who walks through a speeding railroad train.

In an hour the gull flew 10 miles and covered 40. In 5 hours of effortless flying he could have traveled 200 miles, or in 10 hours, 400. If, for the gull, we substitute a land bird and increase the velocity of the wind, we have a natural answer as to how and why migrants, without becoming exhausted, cross the Gulf of Mexico in a single night. They ride the overhead gales that pour spring into the eastern half of the United States.

This explanation was forced on the writer after a spring night 2 years ago. On that night he took an airliner off at New Orleans, bound for Atlanta, in a fresh southerly wind that increased in velocity to 60 miles an hour and shifted to south-southwest at 3,000 feet. Even with throttles pulled back to reduce his air speed, he arrived at Mobile and Montgomery far ahead of time. Northeast of Montgomery the warm air began to overrun cold air at the surface, as scud clouds beneath him attested. At Atlanta he landed down through these clouds into a cold, northeast wind, although the southerly gales were still aloft. The next morning the woods around his home just outside of Atlanta were literally alive with migrants, noisily happy in spite of the cold rain that was falling. There was a natural deduction to be made—the birds had ridden across the Gulf and as far inland as they could before being forced too far aloft by the warm air running up the slope of the cold.

From this deduction it is only a step to the general hypothesis that, whenever possible, migrating birds ride the wind. It is, perhaps, the most natural explanation that can be given, not only for their crossing the Gulf of Mexico on what is a veritable Gulf Stream of the air, but also why they seem to follow rivers on valley winds—why they use mountain ridges and seacoasts when a quartering wind creates a surf that will give them both lift and direction—why the golden plover can ride nonstop from Nova Scotia to South America around the rim of the "Bermuda High" but cannot come back the same way—why land birds caught in a "cold front," or strong windshift, over water must perish because the battling winds will not allow them either to retreat or advance—why migrants land and wait for days with a change of weather, for a change of weather is a result of a change of winds—and finally why the bird's arrival and departure dates fluctuate just as the schedule of the winds fluctuates.

Spring and the birds came early in 1938. Was one the cause and the other the effect? Why not say that both are effects of the same cause—that the influx of tropical air came early in 1938? The birds migrate and the wind migrates. While it is a tilted earth moving in its orbit that is the actual performance, the effect to us is that the sun also migrates. The solar equator comes north in our

spring and goes south in our fall, carrying with it the doldrums, the trade and antitrade winds, and the prevailing winds in both hemispheres. Just as offshore and onshore winds or mountain and plain winds are the effort of nature to equalize temperatures between adjacent areas during night and day, so are monsoons an attempt to balance the heat of the atmosphere over the seasons. Just as land and sea breezes attain their maximum not at midday or midnight but in the afternoon and early morning, so do the prevailing winds flow fastest in spring and fall exactly in time with heaviest migration of the birds. In a large-scale picture the two phenomena appear to fit exactly. Will they also match when examined in detail? The writer believes that they will if we are careful to look at those details from the viewpoint of the bird and not our own.

There can be a wide difference in the two viewpoints. On the night of September 8, the surface wind on the Atlanta airport was 3 miles an hour out of the southeast, while the wind aloft from Washington to New Orleans was out of the northeast quadrant of the compass with an average velocity of 20 miles an hour. While circling the field, the writer turned on his landing lights to warn other pilots of his position. At 900 feet off the ground, two small birds streaked like meteors through the glare of the lights. At 700 feet a third struck the under side of the fuselage with a pistol-like report. Three birds do not make up a migration nor can it be proved that those three were flying downwind. All that is certain is that the air was moving southwest, that there were at least three birds in it, and that a ground observer could have been ignorant of both facts unless he had examined the weather map and the "winds aloft" report and had been able to see the birds against the face of the full moon that was shining.

It is easy to add two and two although the sum obtained may not be the correct answer. It is easy to conclude that migrants ride the wind when birds are found going with it. When it is known that wind and weather are practically synonyms, it is easy to run through "The Season" reports in Bird-Lore and change "cold weather" to "northerly winds" and "warm weather" to "southerly winds" and be pleased to see that migrants arrive with them. When one is looking for just such a similarity it is easy to see the sameness between a map of the migration routes and a map of the pervailing winds. When it is known from experience and study that an advancing cold front crowds and lifts the warm air in front of it, it is natural to assume that bird traffic should be crowded into a wave as automobile traffic is jammed in a bottleneck, and find verification for this assumption in the reports of watchers. To be conservative, it must be admitted that

such similarities between the movement of the wind and the movement of the birds may be indications that the migrants are riding the wind, but they are not proofs.

Positive proof will be difficult to obtain, for it will be necessary to know the starting and arriving points, the exact time and the weather conditions over the entire route at the level at which the birds fly. Most observations must, of necessity, be made from the ground at the very point where conditions are the most likely to be different from those under which the birds travel. Weather not only has length and breadth but height, and the most rapid change is vertically. Temperature, humidity, wind direction, and wind velocity will all be different at 500 feet when there is but little change in miles along the surface. Seacoasts are a vantage point for observations and seacoasts are notorious for windshifts close to the surface. All of this imposes a handicap to proving beyond question that whenever possible birds migrate by riding the wind, but it is a handicap that should work both ways. It should be equally difficult to prove that they do not.

The writer has been told that it is the general belief of bird students that the contrary is true—that, while migrants prefer a quartering wind to the rear, wind and weather are really of little concern to them. If this belief is founded on a correlation of bird movements with surface conditions a shadow of doubt can fall upon the correctness of it. If an observer sees birds from the south land into a cold northeast wind during a warm-front snowstorm, it would be natural to assume that the headwind and the storm meant little to the birds. But somewhere over that observer's head there is certain to be air that has come from the same general region as the birds. Contrary to what our heritage has taught us, snow does not come from the cold, dry regions of the earth but from the warm and moist. The cold air at the surface is only the precipitating agent that is forcing the warm air aloft and chilling it by expansion to the point where it can no longer hold its moisture. As the average slope of a warm front is 1 to 300, the birds can be 90 miles from the actual front and still have a tail wind as low as 1,500 feet.

Just as the observer could be wrong in his deduction while watching descending birds on stormy days, so he could be wrong while watching migrants on clear days when one air mass is in full possession of his territory. The gradient wind tends to follow the isobars, or lines of equal barometric pressure, while surface wind cuts across them at an angle. The truth of this statement can be easily verified by reference to a weather map as meager in details as that which appears in our daily newspaper. Immediately off the surface the wind begins to turn until between 1,700 feet and 3,000 feet it has at-

tained its true direction and velocity. A quartering wind on the ground will, in all probability, be a direct tail wind aloft. Is it not possible, therefore, that bird students have actually observed that migrants prefer tail winds?

Perhaps it is true that they do. Perhaps it is only fancy born of the writer's own natural desire for a clear sky and a tail wind. Whether true or false, there is one fact that is certain: the winds are there for the birds to use. All they have to do is choose. Sir Napier Shaw in his book, The Air and Its Ways, has likened the circulation of the atmosphere to a steam engine run by the heat of the sun. The spinning cyclonic and anticyclonic areas he has called the flywheels of that engine. In his own words, he says, "the constituent parts of the flywheel at any time are the natural airways of the world." He was speaking of aviation when he made the statement but, in the opinion of the writer, he might better have spoken of the birds. Perched on the spinning wheels and the whirling belts, they are riding the natural flyways of the world.



Photograph by Allan D. Cruickshank.

"HE MOVES THROUGH THE AIR WHILE THE AIR ITSELF MOVES . . ."



Photograph by W. H. Nicholson.

1. "A KINGBIRD CAN MAKE LIFE MISERABLE FOR THEM . . ."



Photograph by W. L. Finley.

2. "A QUAIL CLIMBS WITH THE SPEED AND STEEPNESS OF A PURSUIT PLANE . . "



Photograph by Allan D. Cruickshank.

1. "THE DOVE . . . USES LESS ENERGY."



Photograph by R. T. Peterson.

2. HERRING GULL.

BOOKWORMS

By E. A. Back

Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture

[With 18 plates][1]

When one enters such thoroughly modern structures of stone, steel, and cement as the Congressional Library or the National Archives in Washington, D. C., or the Huntington Library in California, to mention only three repositories of documents embodying the best information available to the librarian, he is so overwhelmed by a sense of beauty and permanence that he finds it hard to believe the often repeated statement that insects have destroyed more books and papers than fire and water. Yet the concrete examples of book destruction by insects which have come to the attention of the Federal Bureau of Entomology and Plant Quarantine of the United States Department of Agriculture during the past 15 years leaves little doubt as to the soundness of the belief that insects are in the front rank of book enemies. Persons living in northern climates see less of the ravages of book insects, but no lover of books located in the Tropics need have his attention called to their importance.

Insect attack upon books and papers increases as the climate becomes warmer and more humid. No part of a country such as the United States appears entirely free from library pests. Some of the most serious infestations have been found in little-used libraries in New York City, New England, and the northern tier of States, although the number of such infestations is exceeded by far by those that occur along the Gulf coast northward to the Mason-Dixon line. There is no well-informed librarian anywhere who is not constantly on the watch to detect infestations by insects, either in books already on the library shelves, or in books newly acquired from outside sources.

The importance of insects as destroyers of books has been recognized for years. Many of the earliest manuscripts have been

[1] Photographs taken under supervision of author by Marcel L. F. Foubert, Division of Illustrations, Office of Information, U. S. Department of Agriculture, unless otherwise credited.

destroyed by insects. Among the very early writers, Aristotle, writing in Athens about 335 B. C., mentions creatures in books resembling grubs found in garments. Horace (65–8 B. C.) expressed the fear that his writings would eventually become "food for vandal moths." Ovid (43 B. C.–A. D. 18), while in exile, likens the "constant gnawing of sorrow" at his heart to the gnawing of the bookworm "as the book when laid away is nibbled by the worm's teeth." Moses, addressing Joshua, gave instructions regarding the preservation of the books of the Pentateuch by anointing them with cedar oil and storing them in earthern vessels. Philippus of Thessalonica early in the first century A. D. compared satirically the grammarians of that day to bookworms, thus first voicing so far as is known a comparison now used so often that instinctively one thinks of a very studious person as a "bookworm." Ausonius, who lived in the fourth century A. D., scoffs at the tutor who prefers to bury himself in "worm-eaten and outlandish scrolls" rather than give himself to more familiar pursuits and refers to a choice between preserving writings with cedar oil or allowing them to perish as food for worms. Even Pliny the Elder stated that dust is productive of worms in wools and cloths and "these will breed in paper also," thus giving rise to a theory concerning the generation of worms still believed today by not a few persons. All evidence indicates that insects have always been foes of the written and printed word.

The seriousness of the bookworm problem led the Royal Society of Göttingen in 1774 and the International Library Congress in 1903 to offer prizes for a satisfactory solution. William Blades in 1888 wrote The Enemies of Books in which he has a chapter entitled "The Bookworm." But it was C. V. Houlbert who made the most serious attempt to discuss this group of insects in his book entitled "Les Insectes Ennemis des Livres," published in 1903, doubtless inspired by the prize offered by the International Library Congress held that year in Paris. But when one reviews the long list of articles dealing with book insects, "in fact or fancy," as set forth in the truly fine bibliography of 493 items prepared by Ralph H. Carruthers and Harry B. Weiss and published in 1936 in the fortieth volume of the Bulletin of the New York Public Library, there comes the conviction that book insects are a menace not confined to the past and that their destructive work still continues in libraries of the unwary.

Although bookworms have figured much in prose and poetry, the informed person reading the literature about them must confess that, in the light of modern entomological knowledge, most of the earlier writers had more knowledge of books than of the insects attacking the books. The best works are those that are confined to a discussion of specific instances of destruction by authoritatively identified in-

sects. There has been a tendency at times to record as pests of books insects that harm books only under the most accidental of conditions. This may have resulted from the thorough disregard for the preservation of books and manuscripts known to exist quite generally even as late as a hundred years ago, which sometimes resulted in the storing of books in unsanitary surroundings. It is to be regretted that even today the records of many colonial probate courts and the vital statistics of many small towns and counties, to say nothing of State records in some capitol buildings, are stored in basement rooms so poorly ventilated and insulated against moisture that instances of their injury, and often of their utter destruction, by insects are by no means rare. The late George S. Godard, for years librarian of the Connecticut State Library, preached constantly to the town clerks and judges probate the necessity of exercising great care to house public records where insects, fire, and water could not harm them, and did more than any other one person, in all probability, to bring the valuable town and county records of Connecticut together in the well-guarded State library. One has only to search for early records in many parts of the United States to appreciate how many books of records of historical value have already been destroyed by insects because of improper housing.

Blades, the Englishman, already referred to as writing in England in 1888, states: "Our cousins in the United States, so fortunate in many things, seem very fortunate in this—their books are not attacked by the 'worm'—at any rate, American writers say so." He even calls attention to the statement in Ringway's Encyclopaedia of Printing that in Philadelphia the slightest ravages of bookworms "are looked upon as both curious and rare." Even if this were true in that day, such a state of affairs has long since passed. In the colonial days of this country books were not commonly possessed by the average household in the numbers possible today. In fact, books in many homes were limited to the Bible, church hymnals, American printed histories, and a few school books. These were given such hard usage that bookworms made no headway in them, and the books were so valued that they became a part of many an itemized inventory of a man's estate and were mentioned in his will.

Early writers have done much to instill into the public thought the idea of mystery and elusiveness surrounding bookworms. Often the discovery of a single living grub (pl. 12) has been thought worthy of record. Too few writers have associated the bookworms with very commonplace, cosmopolitan pests of articles of commerce and of stored or refuse vegetable matter and animal matter or with the wood of buildings. The cigarette beetle, responsible for thousands of dollars worth of damage annually to raw and manufactured

tobaccos and upholstered furniture, and the drugstore beetle, which, with the cigarette beetle, is the ever present foe of farinaceous food products—seeds, grains, dried vegetable drug supplies, condiments, and many home furnishings of vegetable origin—are so abundant numerically that at times they swarm from warehouses by the millions and so fill the air that the flying beetles are carried considerable distances by the wind and on the clothing and vehicles of travelers. Others, like termites, cockroaches, and silverfish are such cosmopolitan and constantly injurious pests of the home that they are accepted the world over more as common household pests than as book destroyers.

It is a source of wonder to many that books and old manuscripts can be so badly damaged by insects and yet, when examined, reveal not a living bookworm. So often nothing is readily visible but the havoc left behind by the feeding grubs. More old books will be so found than with active feeding bookworms. There is no mystery, however, in this state of affairs. Nature has provided enemies of bookworms in the form of tiny parasites never seen by the untrained eye. They ferret out the grubs of bookworms and kill them off, and after they have done their work they too pass on to other fields of activity and along come the scavengers of nature, the dermestids such as the cabinet beetle (*Trogoderma*) or the small larvae of the carpet beetles (*Attagenus* and *Anthrenus*), known better to us all as destroyers of carpets and clothing, which devour most of the animal tissues left in the book except the chitinous jaws of the bookworm. In many a book, completely free of bookworms but badly burrowed by them, will be found the remains of cocoons of parasites to indicate the battle for supremacy that occurred perhaps only a year ago, perhaps 50 or a 100 years ago according to the age of the book, date of original infestation, and condition of subsequent storage. Yet, each book, unless too vigorously tampered with by man, carries such evidence that the kind of insect causing the damage can be determined, if not by the naked eye, then surely with the aid of the microscope.

Untreated books often carry bookworms from country to country. Several such instances are interesting to record, for they indicate how careful persons should be in purchasing old books. In 1937 a letter received from St. Leo Abbey, St. Leo, Fla., stated that many books in its library were being ruined by insects. The insect causing the damage [2] proved to be new to science, and a visit of investigation revealed that the injured books had been presented to the Abbey from the estate of Bishop Moore of St. Augustine, Fla., who died in 1901. This fact, supplemented by the statement by the Rt. Rev. Abbot Francis Sadlier, head of the institution at St. Leo, that books in the rectory of the cathedral at St. Augusthine were infested, led the

[2] *Neogastrallus librinoceus.*

writer to visit St. Augustine. With the cooperation of the Rev. I. Nunan and the Rev. John H. O'Keefe, the books of the rectory were examined and found in some instances to be badly infested. Later, the library of St. Joseph's Academy, St. Augustine, was found to be very generally infested. It was also learned that the early cathedral records, including the vital statistics of early inhabitants, had been so damaged by the insects that they were reconditioned during 1937 by the National Archives to prevent their utter destruction. When it was found that books in the public libraries of other Florida cities were not infested with the same insect, everything pointed to the collections of the late Bishop Moore and the cathedral records as the original sources of the infestation at St. Leo and St. Augustine.

Upon further inquiry, it was learned from Father Nunan that Bishop Moore's aptitude for historic research had led him to discover that all the records of the cathedral, including the vital statistics and church furnishings, had been loaded into the ship *Our Lady of Light*, under the command of Don Marcos Capitillo, and carried to Havana, where they arrived February 6, 1764. This effort of the Bishop of Havana, in charge of the Catholic diocese then including the West Indies, Florida, and Louisiana, to protect the possessions of the St. Augustine Mission from destruction by the English when they took over the rule of Florida, resulted in the depositing of the records, in the form of handwritten, bound volumes, in the archives of what is now called Columbus Cathedral in Havana. There they remained until Bishop Moore, discovering them and recognizing their great historical importance to the State of Florida, negotiated their return to the Archives of the St. Augustine Cathedral in the year 1913. As no other books in Florida had been found infested by this destructive bookworm except those originating in the St. Augustine Cathedral or in the house of Bishop Moore, it was suspected that when the records were returned from Cuba, they carried an infestation which later was carried in gifts of books to the Catholic institutions above mentioned. A visit to Havana in 1938 proved the pest to be widely distributed in many book stalls, in the National Library in the Capitol Building, and in the Columbus Cathedral. In the closely guarded archives of the Columbus Cathedral itself some of the unused volumes of old records, some dating back to the sixteenth century, were so badly riddled that the pages could not be turned. There seems little doubt but that this bookworm was introduced into Florida at St. Augustine with the return of the cathedral records after storage in the Columbus Cathedral, Havana, from 1764 to 1913, and that from St. Augustine, infestations were carried to St. Leo, Fla. In 1939 the same insect was found to be causing great destruction in the unused books of the library of St. Charles College at Grand

Coteau, La. This infestation undoubtedly owes its origin to infested books taken there from Havana many years ago.

It is said that there is no finer collection of books and manuscripts dealing with Jewish literature and history than that in the library of the Jewish Theological Seminary in New York City. Many of the ancient volumes have come to this country from those portions of Europe known to be overrun with bookworms. When these books were moved to the new and very beautiful and modern seminary library building in 1933, many were found to be carrying active infestations which had their origin across the Atlantic. A sojourn in this country had in no way impaired their capacity for injury.

While engaged in investigational work in Honolulu, the writer made the acquaintance of the late Dr. William T. Brigham, for many years director of the Bernice Pauahi Bishop Museum, and was shown his valuable collection of books in which he took great pride. After Dr. Brigham's death, these books were boxed and stored in Honolulu for several years until, in 1927, they were sold to a firm of book sellers in Boston. Upon arrival in Boston, hardly a book of the estimated 8,000 volumes, valued at over $25,000, was found free from the ravages of Catorama bookworms. One damaged book is shown natural size in plate 4. It is hard to believe how quickly bookworms can ruin books in certain warm and humid climates and how easily they can be shipped to distant lands. A shipment of books, similarly infested and injured, was received late in 1939 by the Congressional Library from Rio de Janeiro, Brazil.

Not all insects that infest books are true bookworms. Book insects may be divided into three groups: (1) the true bookworms, (2) termites, and (3) surface feeders.

The true bookworms are all tiny creatures (pls. 4, 5). In no stage of their life do they exceed, usually, one-tenth or one-eighth of an inch in length. The adults, almost never seen without a close search, are brownish or blackish beetles. The adult beetles are inconspicuous and are seldom active in the bright light of midday. They possess certain adornments which make it possible to distinguish the species, once the beetles are captured and placed beneath the microscope. In like manner, the white grubs (pls. 4, 5, 12) or immature forms look alike to the average person. When disturbed by the turning of the pages through which they have been building their tunnels, they curl into tight balls and roll out of the book, or roll just enough from their tunnels to be crushed when the book is closed. The grubs hatch from eggs laid by the parent beetles and at once begin burrowing into the covers, seemingly preferring covers in which there is considerable glue, paste, or casein. They frequently center their attack along the backs or hinges of the book covers, cutting the threads which bind the

pages together, thus causing the pages to fall apart (pl. 6). From these original points of attack the grubs, as they get more mature and voracious, extend their tunnels through covers and pages, according to the habit of the particular species, and so line their tunnels and pupal chambers with a gluelike secretion that badly affected books may literally become solid blocks of paper, to be opened only by main strength, and then not without ripping and rending the pages into worthlessness. Even a page as moderately damaged as that shown in plate 8 can be separated from the next page only with care. Some books (pl. 16) must be soaked in clear gasoline before any further attempt is made to recondition their pages.

Fortunately the bookworms most commonly attacking sheepskin and cloth-bound books in law libraries and other collections throughout the United States confine their ravages to the leather and the cardboard of the cover (pl. 15) and seldom burrow into more than a few of the pages closest to the cover. When a number of the grubs are burrowing in leather-bound books left for months without being removed from the shelving, they will push out, from the holes they make in the leather, chewed particles which fall and lie in small heaps on the shelving between the exposed book ends. The excrement of bookworm grubs gathers in their tunnels and between the pages as a fine dust that may be as varied in its color as the differences in the type of paper or the printing ruined by their feeding. From badly damaged books this powder or dust will sift out when the book is shaken over paper and can sometimes be collected by the quart. In plate 12 is shown the well-grown white grub of a typical bookworm surrounded by the dust it has formed as it has eaten out a cavity along the edges of the pages where these are sewed together. All real destruction is caused by the dust-making grubs. The adult beetles which mature close beneath the cover or the edge of the pages escape from the book by eating small round holes as shown in plates 1, 14, 16. The adults must reach the exterior to mate, and they lay their eggs about the covers and edges of the pages.

The insects known as surface feeders are the common household pests—cockroaches, silverfish, and psocids or book-lice. Although psocids are very frequently seen running over books in some libraries and in many homes and have been called lice because they are whitish, tiny creatures, hardly as large as the head of an ordinary pin, their importance as book pests has been exaggerated. They are frail creatures that today are considered incapable of causing physical injury to book covers. Since they do not bite people, carry disease, or harm books, they are objectionable only in the annoyance they may cause nervous persons who do not know that they are harmless. Warmth and dampness favor their increase.

Cockroaches and silverfish are world-wide in their distribution. They can seriously deface book covers but rarely do more, even when most abundant. They do not eat into the pages of books: they eat the sizing out of book covers. If these are of paper, the insects may actually devour the paper itself as indicated in plate 7, where an envelope is shown ruined by silverfish. But usually both silverfish and cockroaches confine their attack to removing the sizing from cloth bindings as indicated in plate 2 or to eating off labels pasted onto books or files (pl. 13, c). The large American cockroaches may become very destructive in closed library spaces and may actually eat off the backs of cloth-bound books (pl. 13, a). Cockroaches emit an inklike liquid which further defaces books (pl. 13, b). No one can sympathize with the librarian in northern climates who permits cockroaches and silverfish to deface books, for the presence of these insects in numbers is the result of neglect for which there is no excuse. But in tropical areas, or even in the Gulf coast States, where cockroaches and silverfish are abundant everywhere outdoors as well as indoors, the protection of books from defacement is a continuing battle that is won only by eternal watchfulness and application of remedial measures.

Termites have ruined more books than any other group of book insects. There are two kinds, the subterranean and the dry-wood termites, which, however, look very much alike (pl. 3, a, c). Because the worker forms, which cause injury, are creamy white in color, they are frequently called "white ants," although they are very distinct from true ants, which do not harm books. Termites are never seen running about over books and furniture unless their feeding chambers have been broken open. The subterranean forms are so called because they must maintain contact with the moisture in the soil beneath the building in which they are causing destruction. In modern libraries built with the intention of "building termites out" and equipped with metal shelving, the subterranean termites cause no harm. It is true that cracks in basement floors and side walls may offer entry to subterranean termites even into buildings thought to be termite-proof, but it requires little inspection to guard against such attack. Usually, subterranean termite destruction takes place in libraries in wooden buildings with books stored on wooden shelving. In private homes, or in public institutions that store valuable old records in basement rooms, or even on first-story floors, termites may attack with a suddenness that is astonishing. Their natural food is wood, which is cellulose, but the pages of many books are also cellulose. Private collections of books left packed in wooden boxes over wooden basement floors infested with termites have been ruined during a four-months' storage period. Types of injury caused by

subterranean termites are indicated in plates 9 and 10. No two books will show the same pattern of destruction, but subterranean termite injury can be identified by the thin deposit of mud with which the termites line the cavities eaten out in books. This mud is formed from earth particles carried from the soil beneath the building in which the damage has occurred and is used as a plaster to air-condition the termite home.

Dry-wood termites require no contact with the soil and may be destructive wherever they occur. Fortunately, instead of being found in most parts of the United States as are the subterranean termites, they are more tropical forms and are found mainly in tropical areas, being troublesome in the United States from Charleston, S. C., southward. In southern Florida, Cuba, and parts of California, and in Hawaii and the Philippine Islands, they are destructive. They do not line with mud the cavities they eat in books, but can be identified at once by the peculiar appressed whitish or tan pellets of excrement which will flow in a stream from a book as it is opened (pl. 3, b). The cavities that they eat into books are of endless variation as to size and contour (pl. 11).

Although more instances of injury by insects to books have been recorded during the past few years in private homes, the ravages of book insects have been greatly lessened in large public and private institutions, where much attention is being given to perfecting methods designed to eliminate insects. Subterranean termites have been eliminated from modern termite-proofed buildings using steel shelving. Modern construction and care in selecting shelving without open hollow spaces that can be used as hiding places for cockroaches and silverfish make possible the complete subjection of these defacers of books in most parts of the country. The National Archives has installed modern vacuum fumigation vaults in which every lot of newly acquired material is fumigated for the destruction of insects before it is allowed to be unpacked. These steel vaults, two in number, are shown in plate 18. Each vault is 4½ by 5½ by 11 feet. As told by Arthur E. Kimberly, Chief of the Archives' Division of Repair and Preservation:

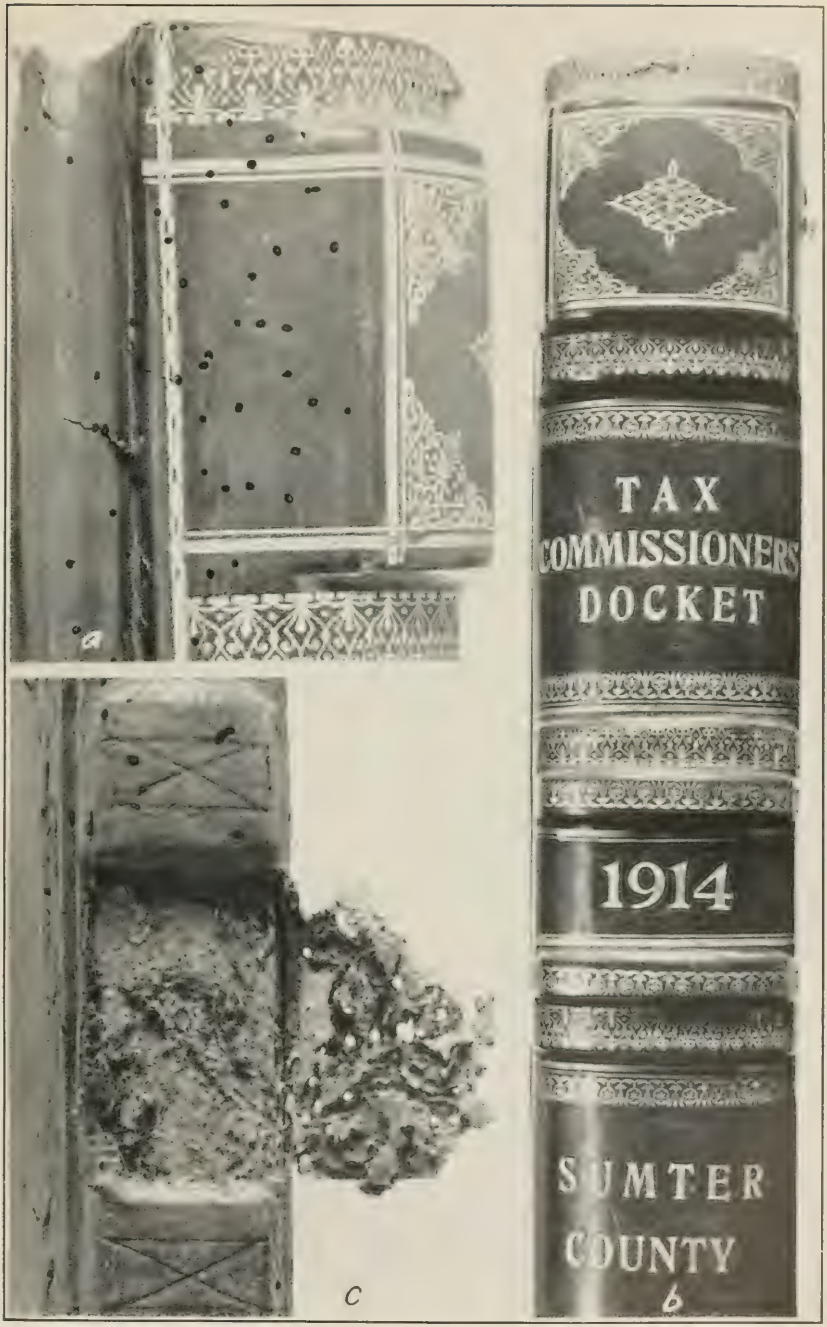
> The records are placed in a vault in their original containers and the vault is evacuated until a vacuum of approximately 29.9 in. of mercury is obtained. A mixture of ethylene oxide and carbon dioxide is then released into the chamber until the vacuum falls to 21 in. of mercury. The gas is then agitated for 15 minutes by pumping it out at the top and in at the sides of the chamber. After the records have been exposed for a total of 3 hours the chamber is reevacuated to 29.8 in. of mercury, the vacuum is broken with air, and the fumigated materials are removed.

This method was developed for destroying insects in agricultural products by the experts of the Bureau of Entomology and Plant

Quarantine of the United States Department of Agriculture. It was first applied to the fumigation of books in a library by Thomas M. Iiams, who has charge of the preservation of rare books and manuscripts in the Huntington Library. The cylindrical vacuum fumigator installed in 1931 at that library is shown in plate 17. Although vacuum fumigators are expensive and may represent an outlay greater than is practicable for smaller institutions, all libraries and book lovers can arrange to treat effectively in small rooms, or even in very tight chests, books requiring treatment for the destruction of borers or bookworms within their covers and pages.

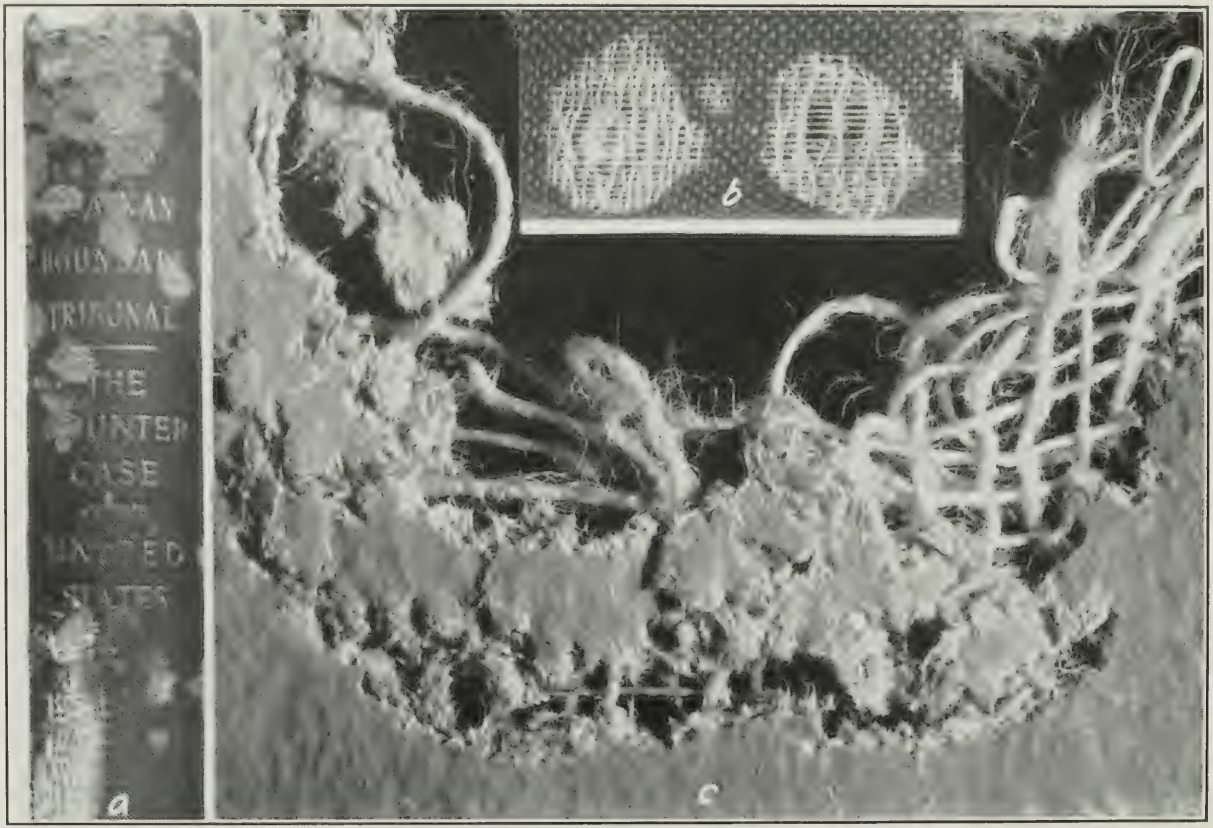
The insects responsible for some of the most serious infestations in books as they stand on the library shelves have been effectively destroyed in 24 hours by fumigation of the library space as a single unit; and this method of combating bookworms is highly recommended when funds are available for the employment of a professional fumigator. The writer knows of no instance where such fumigation has failed.

For libraries loaning books that must be subjected to all sorts of conditions in homes, or for home owners themselves, there have been perfected formulas for washes that may be applied to book covers to prevent or retard the attack of insects. A letter of inquiry addressed to the United States Department of Agriculture, Washington, D. C., will bring details of treatment. It should always be remembered in combatting book insects that frequent inspection of books, and prompt action if insects should be found, will prevent the ruin of valuable books.



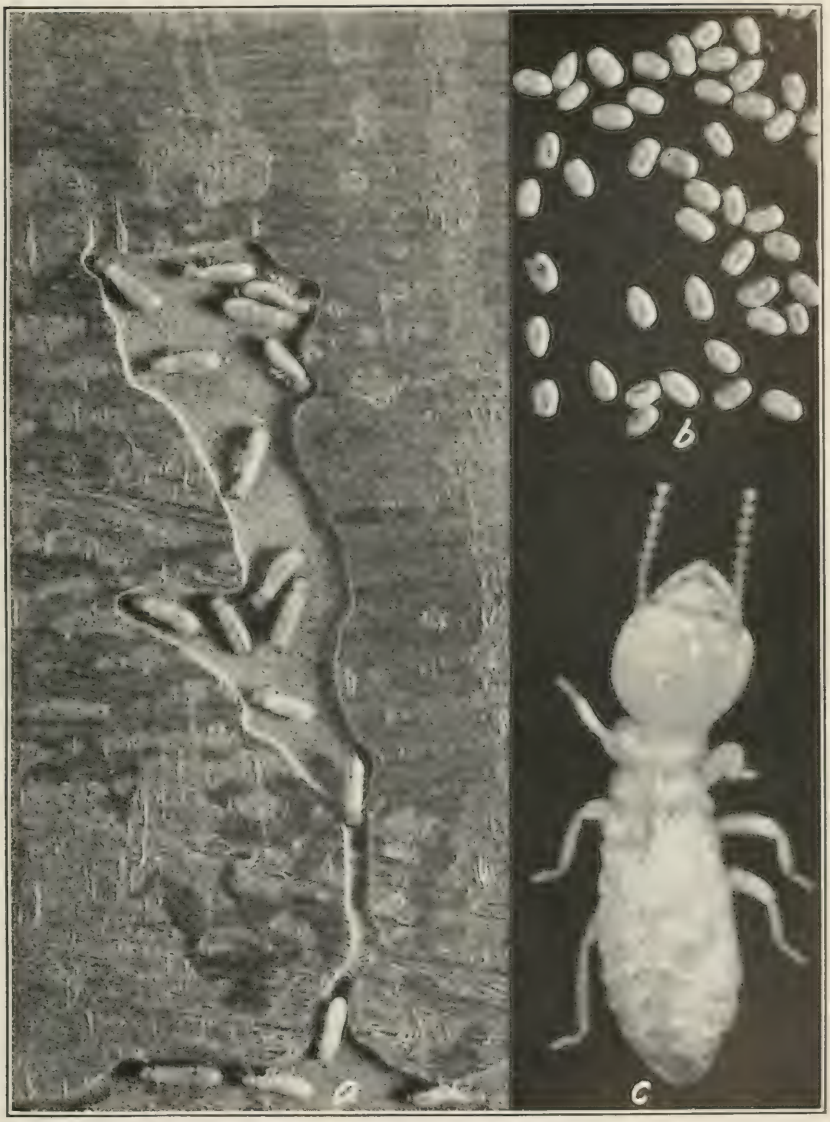
TAX BOOKS DAMAGED BY THE DRUGSTORE BEETLE (STEGOBIUM PANICEUM).

a and *b*, Two views of excellently bound book, showing exit holes in leather made by escaping beetles; *c*, portion of back of an older book removed to show typical damage to cover. (Figures *a* and *c* slightly reduced in size.)



DAMAGE TO CLOTH-BOUND BOOKS BY THE AMERICAN COCKROACH (PERIPLANETA AMERICANA).

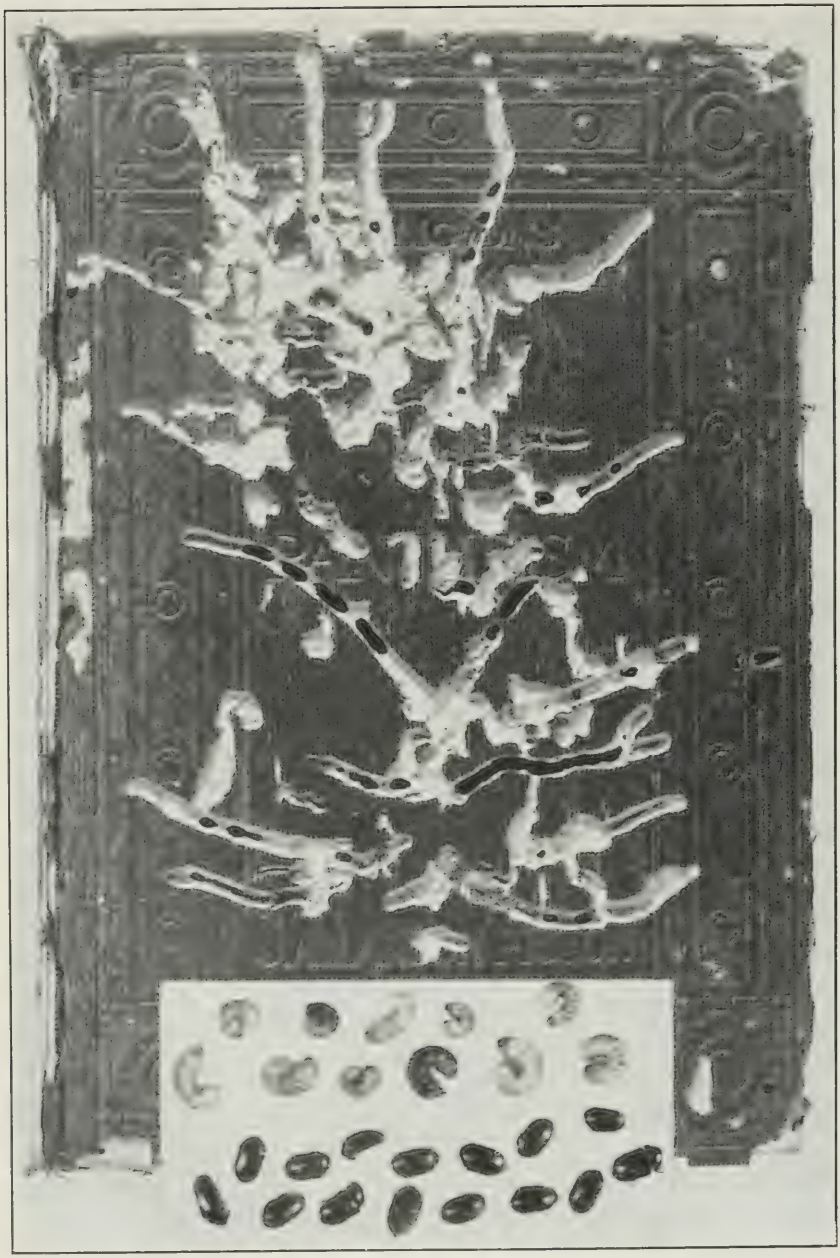
a, Back of book injured (natural size); *b*, eaten spots enlarged to show the removal of the sizing by the cockroaches from the cloth; *c*, damaged spot of a cover greatly enlarged to show not only removal of sizing, but also destruction of cloth foundation.



Photograph by J. G. Pratt.

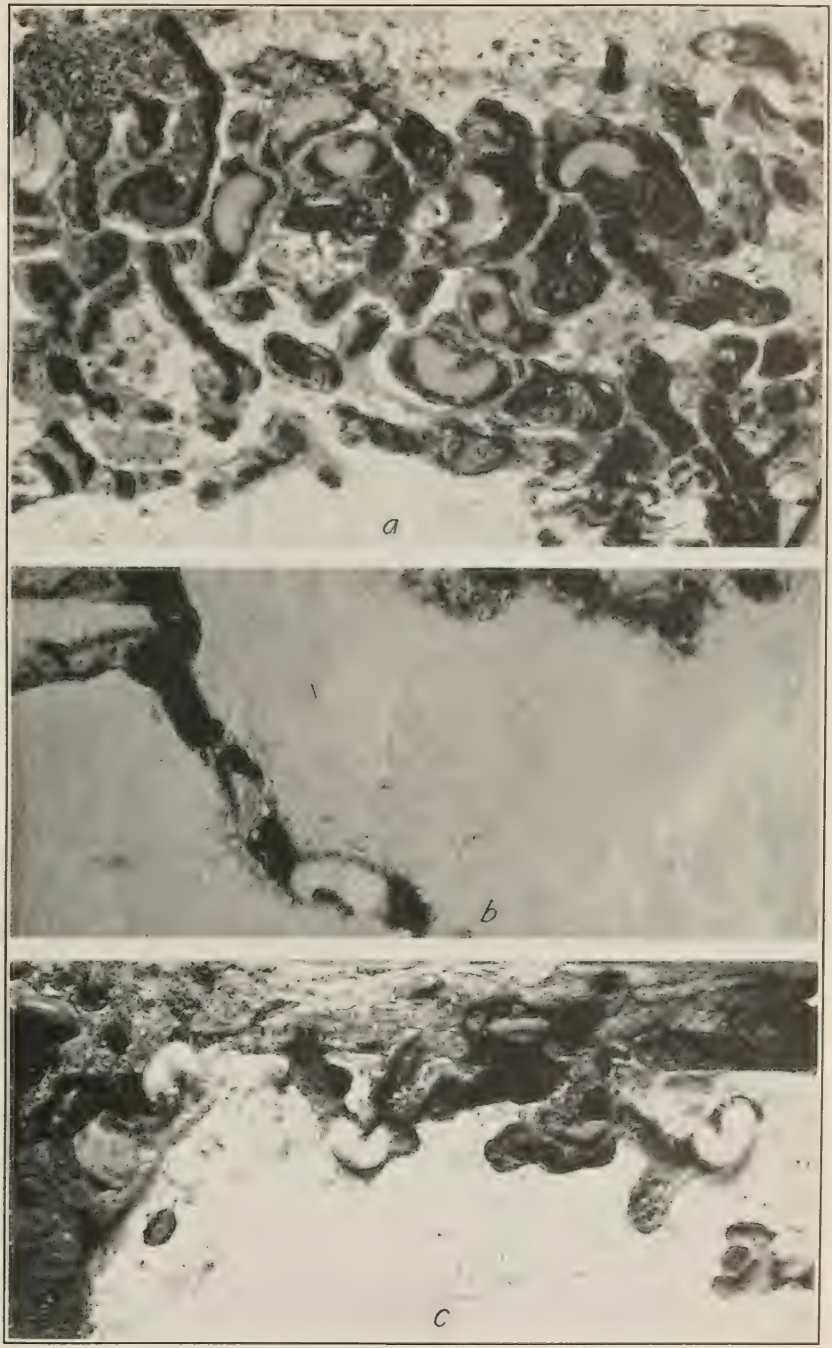
TERMITES.

a, Dry-wood termites in a recently made cavity in wooden bookcase; *b*, excretal pellets of dry-wood termites; *c*, a young termite.

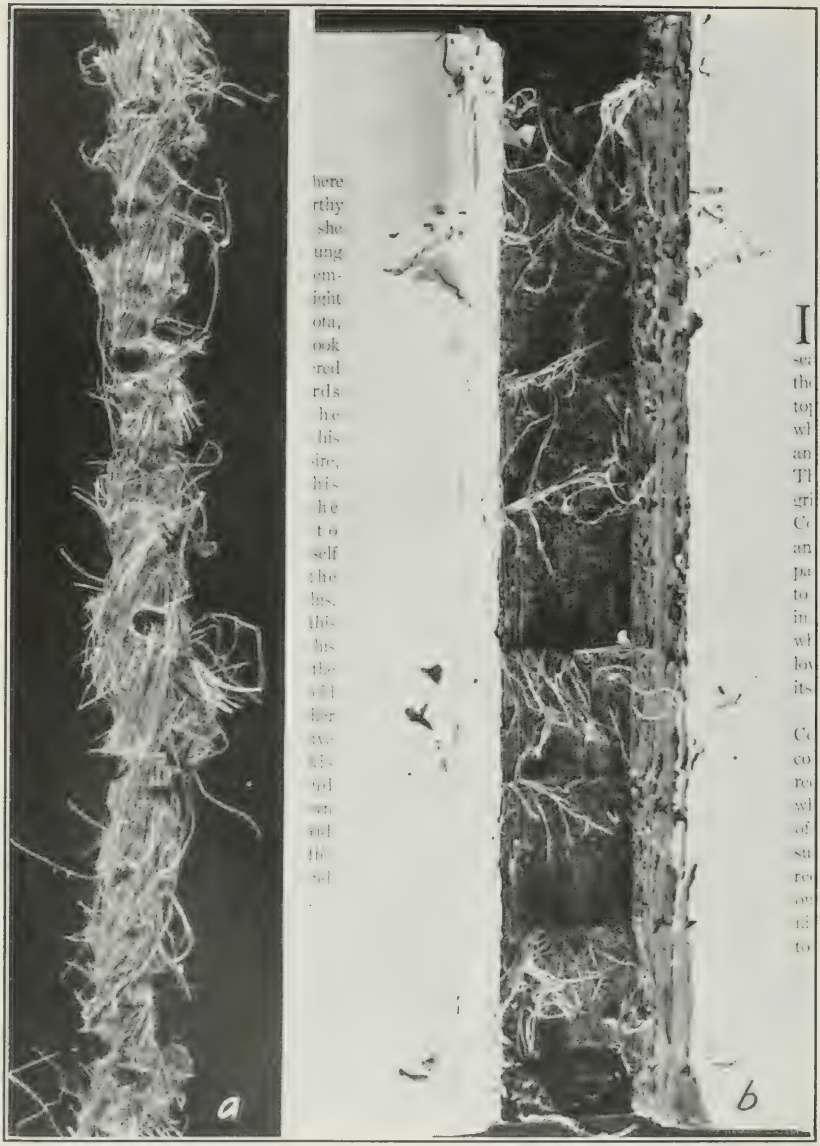


BOOK. NATURAL SIZE, SHOWING THE DESTRUCTIVE BURROWING OF THE HAWAIIAN CATORAMA BOOKWORM.

Insert: Larvae and adults of Catorama bibliothecarum. (2 × natural size.)

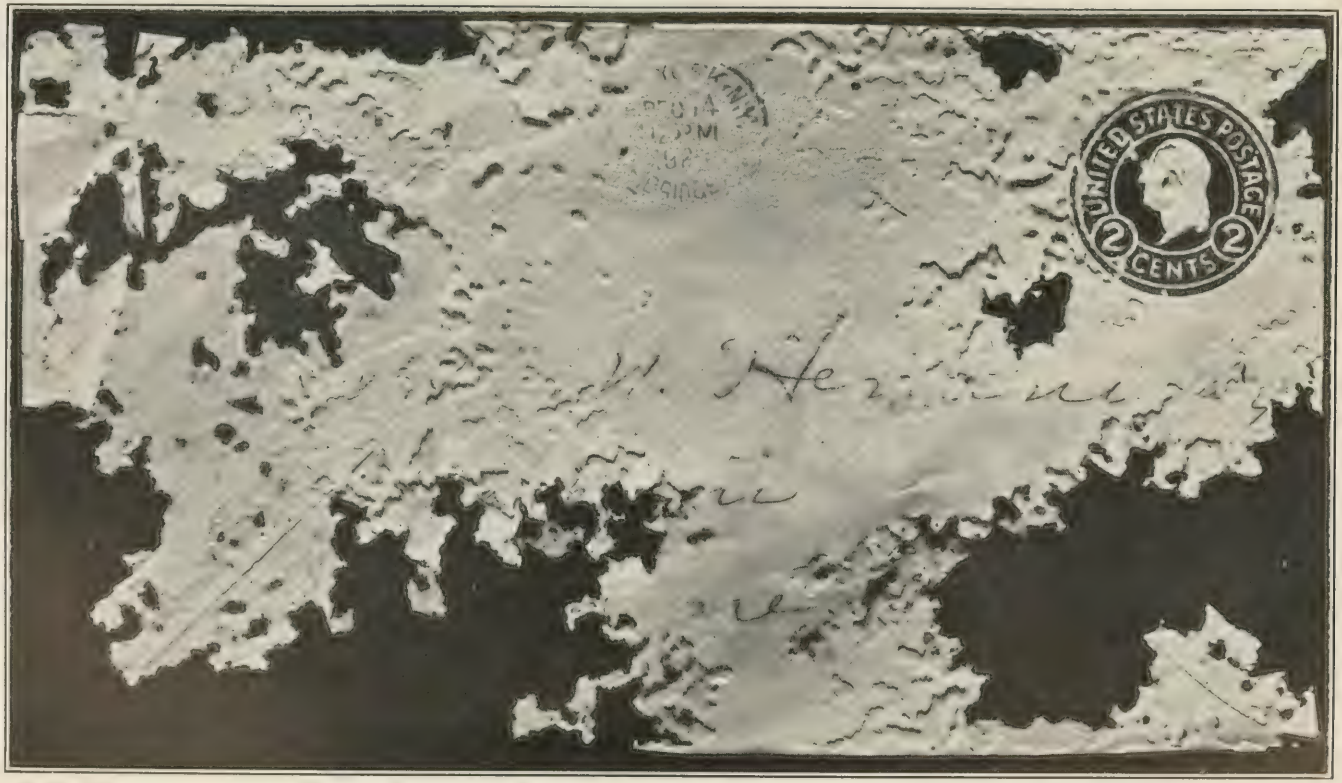


a, Pages of book ruined by feeding of grubs of *Neogastrallus librinocens*. Eight larvae are shown in cells in which they are about to transform to the adult beetle stage. *b*, A single feeding grub of *Gastrallus laevigatus* in the burrow it has made; *c*, four grubs and four adults of the drugstore beetle, *Stegobium paniceum*.

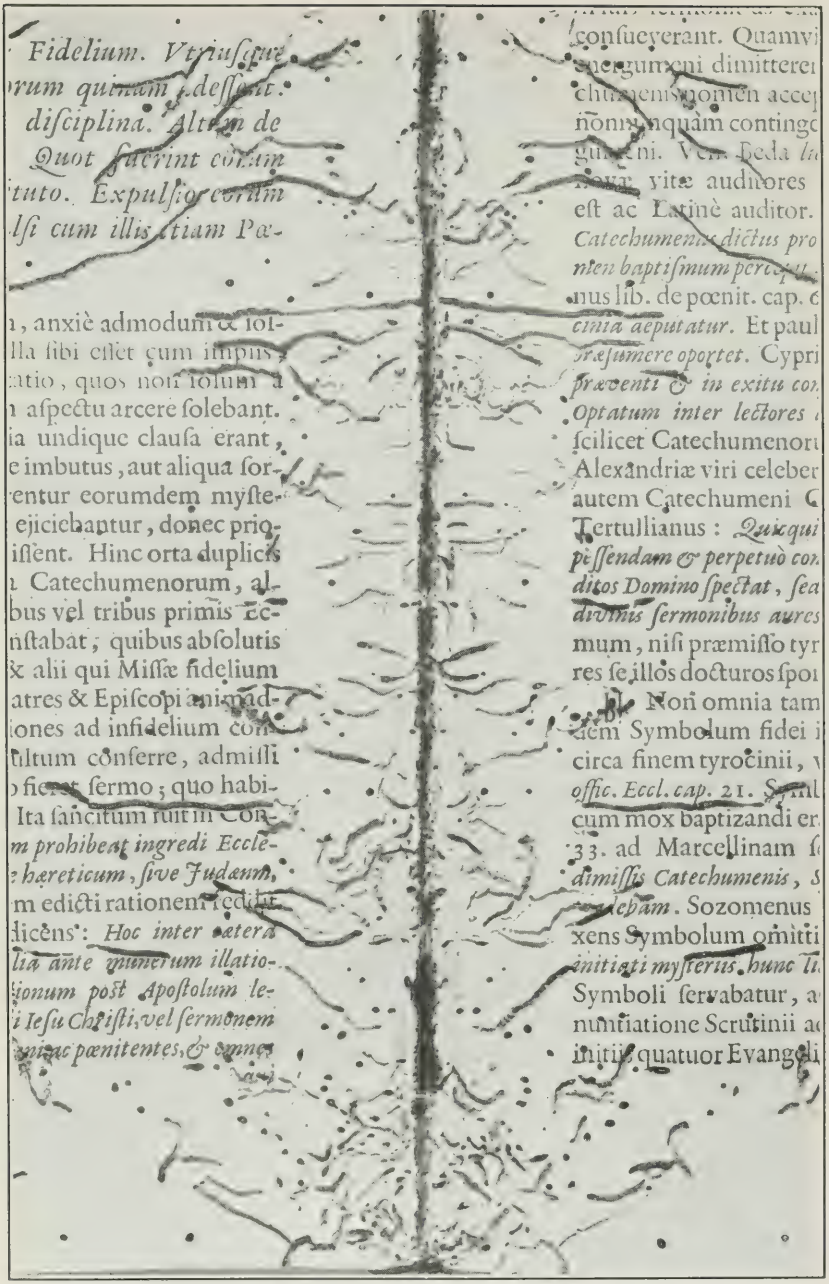


BOOKWORM DESTRUCTION OF THREADS USED TO BIND PAGES OF BOOK TOGETHER, CAUSING THE PAGES THUS FREED TO FALL OUT.

a, Left, heavy jute thread from sack damaged by larvae of *Lasioderma serricorne*, indicating ease with which threads are cut and ruined by bookworm larvae as they burrow in books.



ENVELOPE EATEN BY THE SILVERFISH "LEPISMA SACCHARINA."

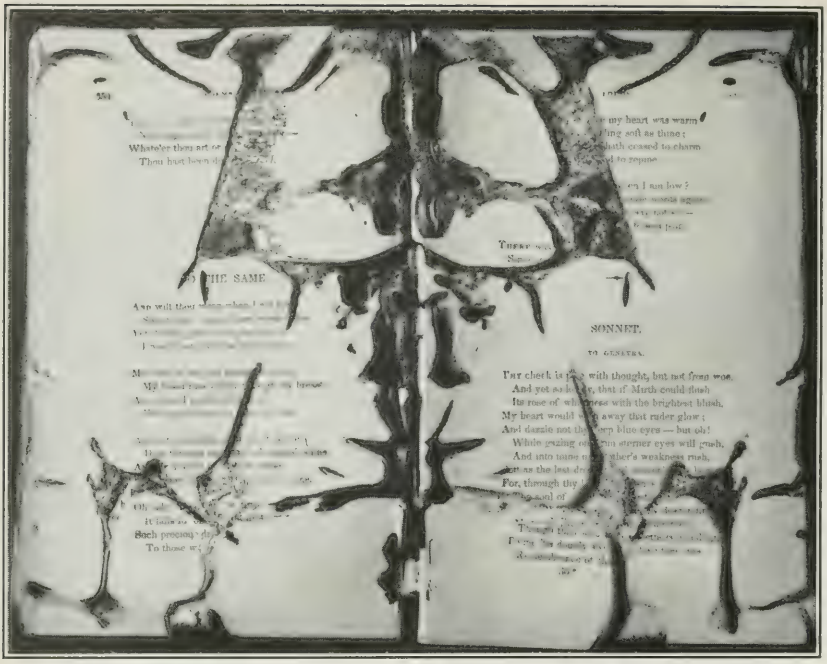


OPENED BOOK, INDICATING DESTRUCTIVE FEEDING BY "NEOGASTRALLUS LIBRINOCENS."

Pages thus injured can be turned only with great difficulty because of the gluelike secretion with which the bookworms line some of their cavities.



TWO BOOKS, SHOWING EXTERIOR EVIDENCE OF ATTACK BY SUBTERRANEAN TERMITES.



1. BOOK OPENED TO SHOW HAVOC CAUSED BY SUBTERRANEAN TERMITES.
(½ natural size)

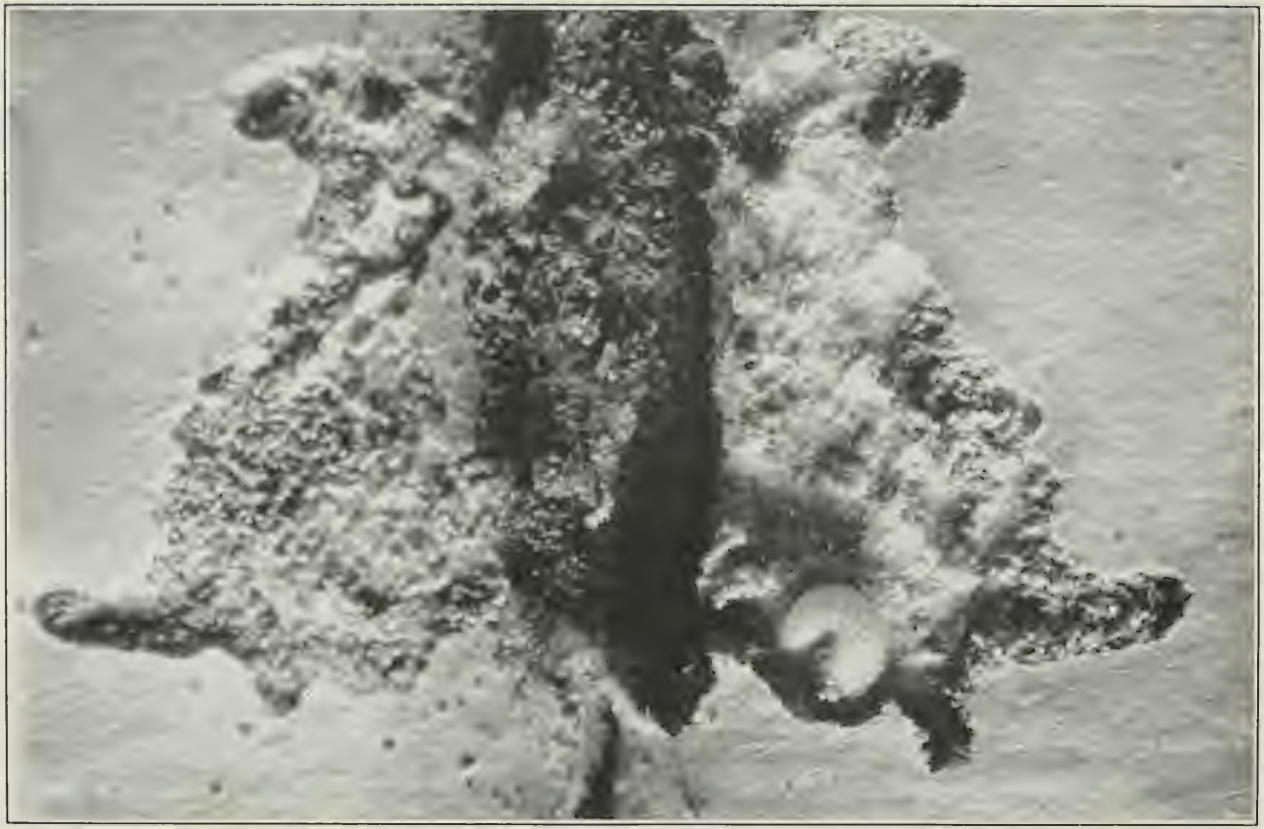


2. INDICATING HOW THOROUGHLY SUBTERRANEAN TERMITES CAN DESTROY RECORDS NOT PROPERLY GUARDED.

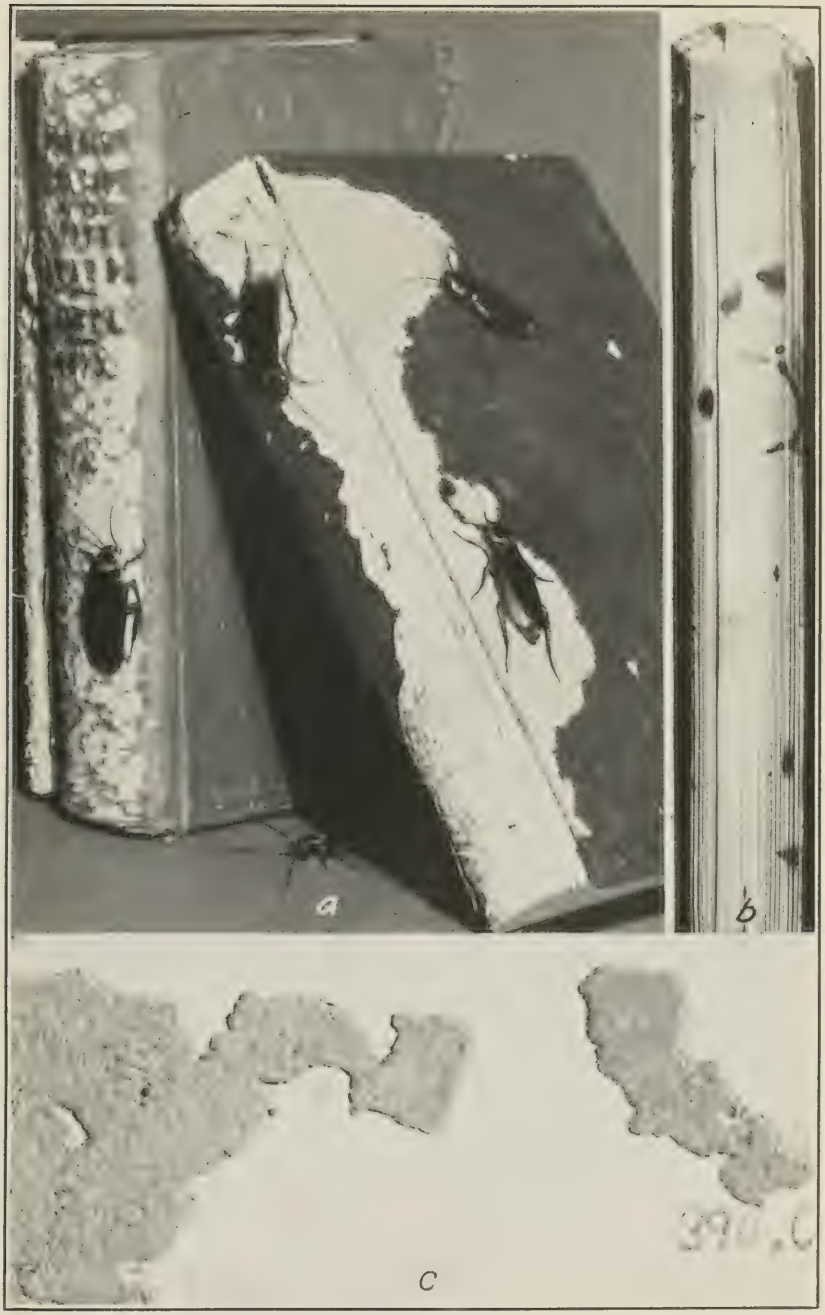
Note thin deposit of mud lining burrows in this and above illustration. (½ natural size.)



BOOK OPENED TO SHOW THE EVER VARIED FEEDING CHAMBERS OF DRY-WOOD TERMITES.



A Book Opened To Expose a Single Well-Grown Bookworm Grub ("Lasioderma serricorne")
Note havoc it has caused along the stitching of the book, and the pellets of excrement or "dust." (6½ × natural size.)



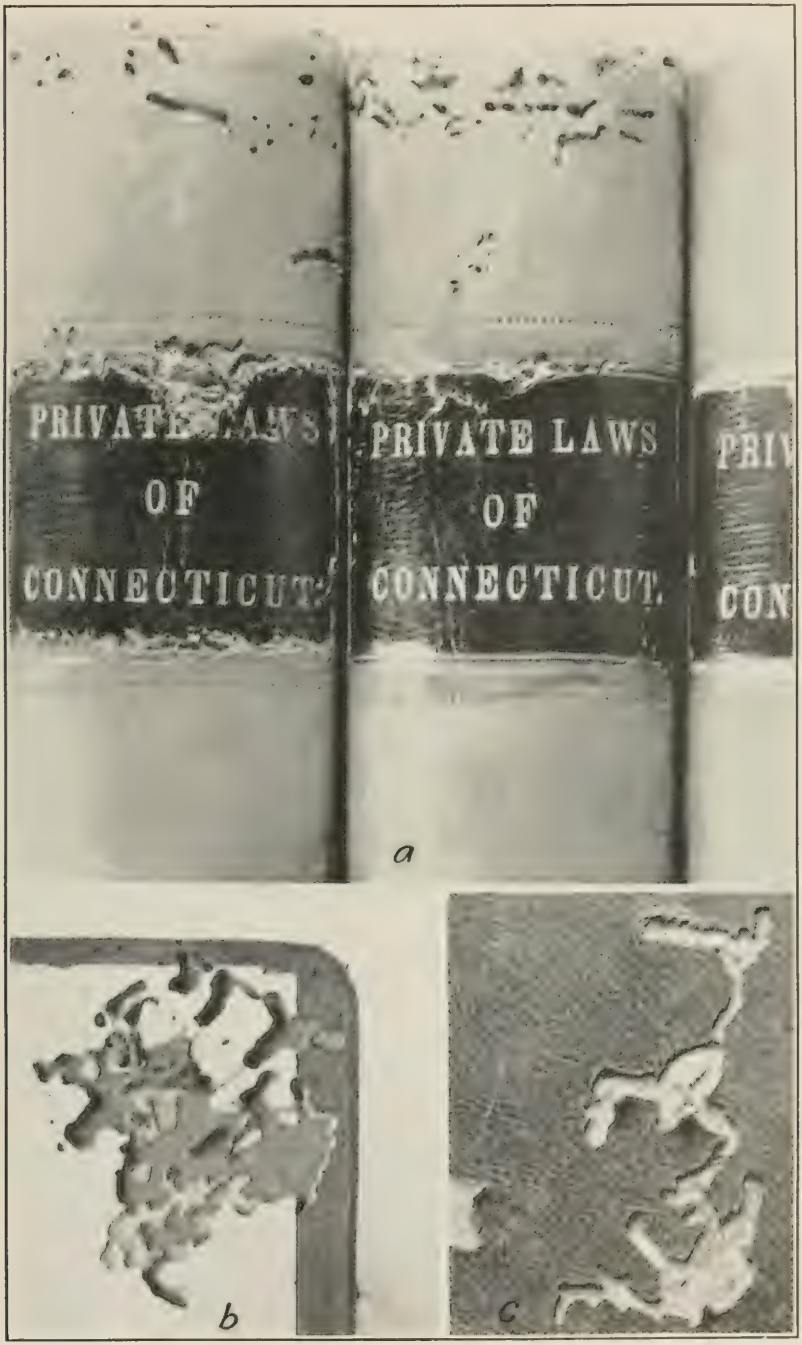
DAMAGE DONE TO BOOKS BY THE AMERICAN COCKROACH "PERIPLANETA AMERICANA."

a, Showing the cloth binding eaten from the backs of two books; *b*, inklike stains on edges of pages; *c*, label of book file damaged by cockroaches.



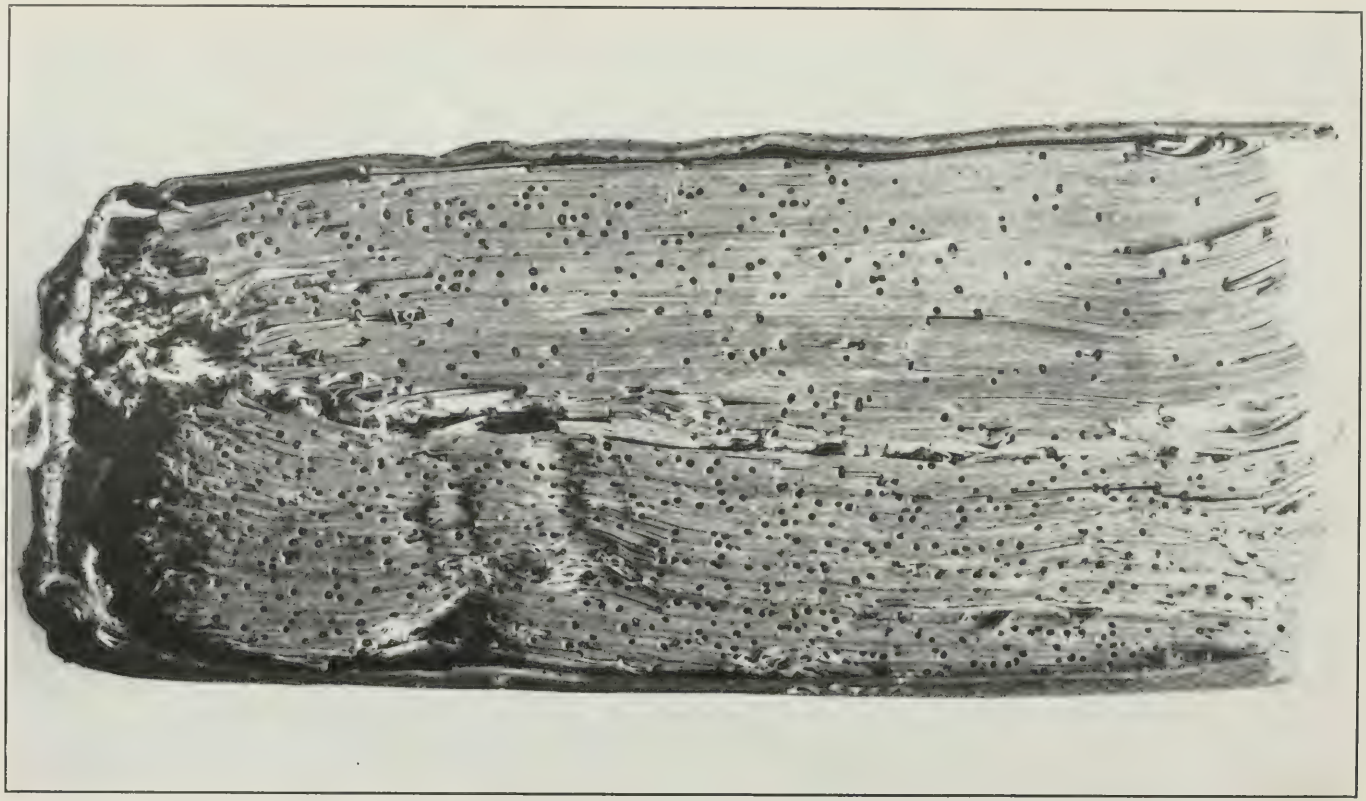
LEATHER-BOUND LAW BOOK DAMAGED BY THE BOOKWORM "LASIODERMA SERRICORNE."

a, Showing burrows of grubs beneath the labels; *b*, outward appearance of labels showing the small, round holes permitting escape of adult beetles from the burrows shown in *a*.



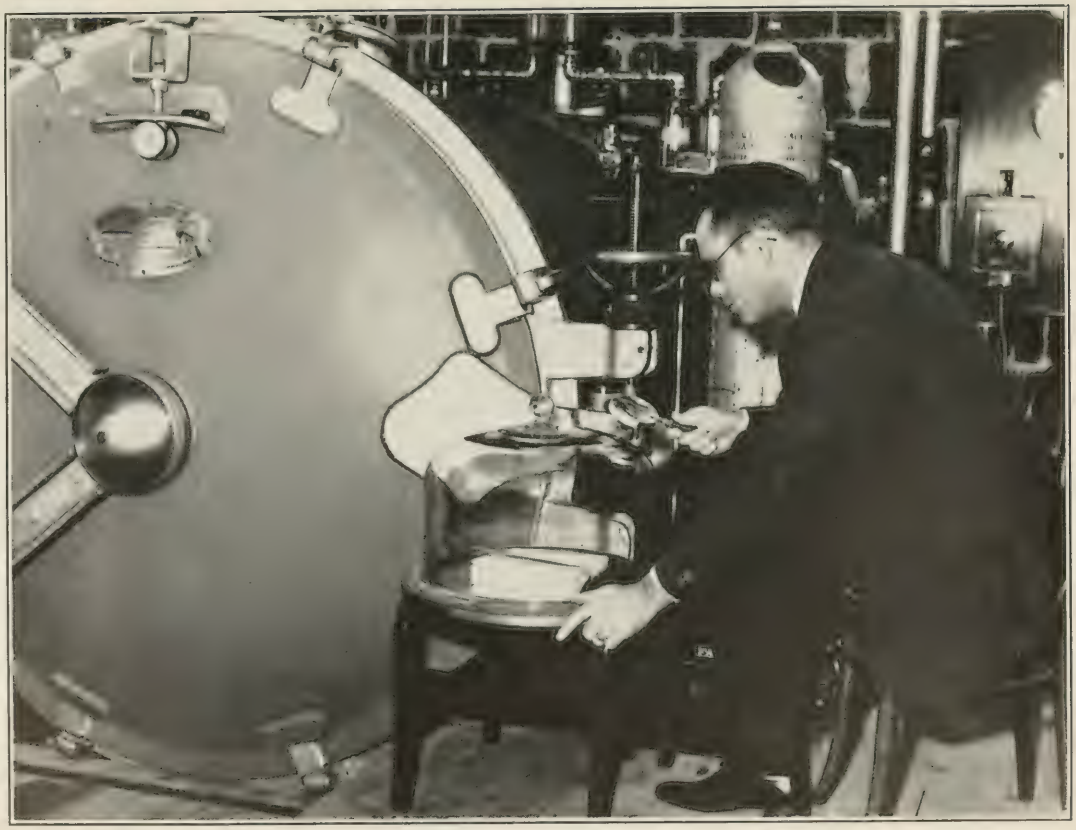
SHEEPSKIN-BOUND STATE RECORDS.

a, External appearance of books damaged by the drugstore beetle, *Stegobium paniceum*; *b*, burrows of the grubs on inside of cover; *c*, burrows in outside of cover where two books are closely appressed.



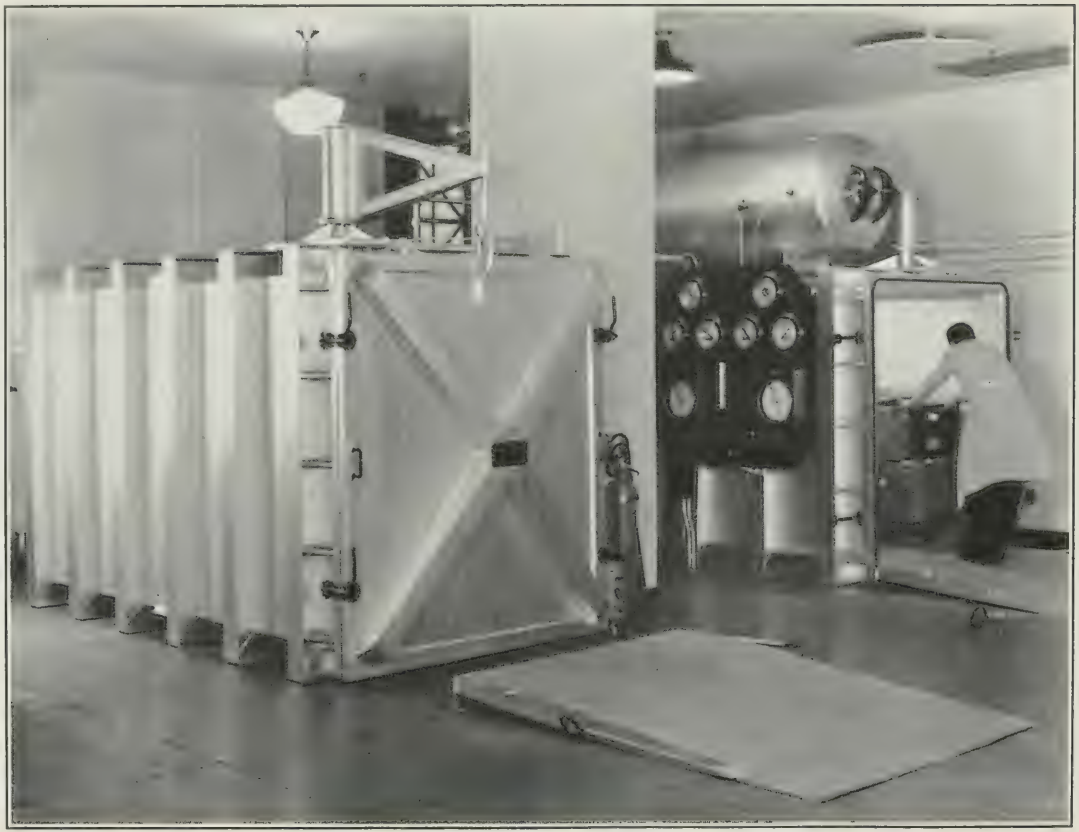
END VIEW OF BOOK INFECTED BADLY WITH "NEOGASTRALLUS LIBRINOCENS."

The pages of this book were so badly honeycombed and cemented together by bookworm grubs that they cannot be turned. The book had to be torn open through the center by main strength.



VIEW OF CYLINDRICAL STEEL VACUUM FUMIGATOR INSTALLED IN THE HUNTINGTON LIBRARY.

At right, T. M. Iiams recording the effect of a fumigant upon a bookworm in book shown under glass bell jar.



TWO MODERN RECTANGULAR VACUUM FUMIGATORS INSTALLED BY THE NATIONAL ARCHIVES FOR THE TREATMENT OF ALL INCOMING MATERIAL TO DESTROY INSECTS.

THE PROBLEM OF CONSERVING RARE NATIVE PLANTS [1]

By M. L. Fernald, D. C. L., D. Sc.

Fisher Professor of Natural History and Director of the Gray Herbarium Harvard University

[With 7 plates]

In the autumn of 1765 John Bartram and his son William discovered near the Altamaha River in Georgia a splendid low tree or tall shrub which, raised in the Bartram Garden, proved to be a close relative of the Asiatic *Camellia*. So handsome were the richly fragrant white flowers, described as 5 inches across, that, in the words of Humphrey Marshall, "William Bartram, who first introduced it, * * * has chosen to honour it with the name of that patron of sciences, the truly great and distinguished character, Benjamin Franklin." Writing of it in 1773 William Bartram said:

> I have traveled by land from Pensylvania to the banks of the Missisipi, over almost all the Teritory in that distance between the Seashore & the first mountains, cross'd all the Rivers, and assended them from their capes a many miles, & search'd their various branches Yet never saw This beautiful Tree growing wild but in one spot on the Altamaha about 30 miles from the Sea coast neither has any other person that I know of ever seen or heard of it.[2]

Because of the great beauty and delicious fragrance of its flowers *Franklinia* (pl. 1, fig. 1) was in great demand in horticulture. It is recorded that from 1787 to 1789 London nurserymen were ordering hundreds of plants from Humphrey Marshall and his nephew and partner, Moses Marshall. In 1790, the year of Franklin's death, Moses Marshall visited the Altamaha, presumably to fill commercial orders, and it is generally conceded that he was the last person to see *Franklinia* in its native haunts. Whether the wild shrubs and trees were greedily exterminated by Moses Marshall for commercial gain or whether the genus was already so near its natural end as a living tree that other factors closed its existence we shall never actually

[1] The original address upon which the present paper is based was given before the Franklin Institute of Philadelphia, on Friday, May 20, 1938, under the title, "Must all Rare Plants Suffer the Fate of Franklinia?" The original paper, of which this is an amplification and modification, was published in the Journal of the Franklin Institute, vol. 206, No. 3, September 1938.

[2] From mss. at British Museum (Nat. Hist.) quoted by Harper and Leeds in Bartonia, No. 19, p. 2, 1938.

know. The bald fact is that Moses Marshall, in 1790, was the last man to see it growing where nature had preserved it through millions of years.

Franklinia,[3] as stated, is related to the Asiatic *Camellia*. It belongs in a natural family of shrubs and trees displaying the amazing disruption of range shown by hundreds of eastern North American groups which, in Cretaceous or Tertiary time, had a wide distribution across Eurasia and North America. Owing to the climatic and physiographic changes accompanying late Tertiary uplifts of western America and various parts of Eurasia, followed by the refrigerations of Pleistocene glaciations, these hundreds of groups have now disappeared from living floras except for disrupted remnants, sometimes in southeastern Europe, but more generally in southern and eastern Asia and in eastern North America. As long ago as 1750, Halenius, in his doctor's thesis defended before Linnaeus at Upsala, pointed out this similarity in the floras of eastern Asia and eastern North America, but it remained for the genius of Asa Gray to bring this relationship vividly before the scientific world.

Many closely related, if not identical species of this eastern or southern Asiatic and southeastern North American relationship are in no danger of extermination: such groups, for instance, as *Liriodendron*, the tulip tree, *Hamamelis*, the witch hazel, *Sassafras*, *Nyssa*, the sour gums, and *Symplocarpus*, the skunk cabbage. Others, however, after millions of years of competition with more youthful types, have retained such tenuous footholds in America that they are rightly looked upon as last remnants of the ancient flora which have grown old where they now linger but which lack the capacity to resist the invasions of more youthful or aggressively dominating genera and species, and least of all the invasion of "that most destructive of all creatures, 'man.'"[4] Many of them are the rarest of plants and some of the most remarkable have already suffered the fate of *Franklinia*.

In order to make quite clear the varying capacities to meet present conditions of plants in the wild (and, I take it, a parallel grouping can be made of mammals, birds, and lower groups of animals), it is necessary briefly to consider the composition of the wild flora of eastern America. To the layman the words "plants"

[3] The late C. S. Sargent placed *Franklinia* in the genus *Gordonia*, as *G. altamaha* (Bartr.) Sargent. Melchior, however, reviewing (in Die Natürlichen Pflanzenfamilien, 1925) the whole family Theaceae, with 23 genera and about 380 species, maintains *Franklinia altamaha* Bartr. as a monotypic genus and in a different subtribe from the chiefly Asiatic genus *Gordonia* (with 1 North American, 30 Asiatic species). This statement seems important, since a correspondent of horticultural journals, seeking to discredit the statements in the original paper, asserts that I am in error in maintaining *Franklinia* as a genus.

[4] Scharff, R. F., Distribution and origin of life in America, p. 194, 1912.

and "flora" too often mean garden flowers, farm crops, timber trees, and weeds. These, although the most obvious of plants, are to the thoughtful student the least interesting, unless, perchance, his outlook is strictly pragmatic.

By far the most familiar element in our wild flora in the neighborhood of old settlements is the great population of weeds. Brought chiefly from the roadsides, fields, and waste lands of Europe within the last three centuries, they are covering the disturbed soils of large sections of the North American continent: Common dandelion, burdocks, daisy or white weed, witchgrass, mustards, hawkweeds, wild carrot, Canada thistle, bull thistle, common plantain, English plantain, pigweed, docks, smartweed, and many others, including the various cultivated (and escaped) fodder plants, like the clovers, timothy, and orchard grass. The invasion of newly disturbed or cleared land by the hawkweeds (devil's paintbrush, king devil, and others), dandelion, witchgrass, and others of their ilk is too obvious. They are the youngest species of our flora, the rapidly reproducing, aggressive, uninvited, and unrestrained vagrants, the ultrademocratic and unsophisticated intruders. Their number is well over 1,000, and their army is reenforced by every arrival of uncleaned European seeds, in the stockings, trouser-bottoms, skirt-hems and blankets of immigrants, in the litter and old straw used in packing from abroad. Arrived in a new country they know no restraints and after a short period of adjustment become the bulk of our plant population wherever natural conditions have been destroyed, and they will even invade and obliterate relict colonies of our original native flora.

There is no possible question of the present-day biological success of the introduced weeds. When I was a boy in Maine, in the late seventies and early eighties, one of the beautiful garden perennials, raised in a few favored borders and coveted by all who had flower gardens, was *Hieracium aurantiacum*, a plant with broad clusters of orange and scarlet tassellike erect heads. It was handsome and at that time unusual, and it was scrupulously shared only with those who would really appreciate and nurture it, as Venus' paintbrush. Soon, however, in the eighties and early nineties, it had become acclimated and began to appear in the fields. It has now ruined thousands and thousands of acres of fallow field and clearing from the tip of Gaspé to Michigan and southward to Pennsylvania; and, whereas it first came to America as Venus' paintbrush, it is now known to all farmers as devil's paintbrush. Furthermore, in that wonderful region containing Oakes Gulf, Bigelow's Lawn, and the Alpine Garden on Mount Washington, where are assembled a great colony of the rarest of arctic-alpine species of plants (of most great groups), small mammals, and insects, the devil's paintbrush repeatedly comes in from below. Only by close watching by the few who

appreciate a choice and distinctive habitat can it be kept in restraint. Similarly, in the bleak alpine chimneys of the high mountains of Gaspé, the home of a splendid colony of rare alpines, another of the vagrant hawkweeds, this time the king devil, blows in from the lowland fields. The last time I visited the mountains I carefully exterminated all the king devil I found—there suppressing or crowding out *Cassiope*. It is feared that no one has subsequently done such policing there.

One of the handsomest plants of pastures, hillsides, and open mountain slopes of the British Isles is a large groundsel (*Senecio Jacobæa*), known as ragwort or by 50 other local and colloquial names. One of its older cognomens was the dignified St.-James's-wort (whence the Latin name.) In the late seventies St.-James's-wort appeared as a waif or stowaway on ballast, thrown out from a ship at Pictou, Nova Scotia. For several years it remained a local colony; but by 1884 it had begun to spread along the local roadsides; by 1900 it had become one of the worst pests of northern and eastern Nova Scotia, eastern New Brunswick, and Prince Edward Island. Browsing animals avoid it and it has full sway, completely dominating, along with one or more of the European hawkweeds, much of the cleared land of the Maritime Provinces, where no one now calls it St.-James's-wort; it is everywhere appropriately known as "stinking Willie." Soon after 1900 stinking Willie reached the waste land about the union station in Portland, Maine, and it now colors a pasture slope in Essex County, Mass.

Among the most remarkable elements of the flora of eastern North America are the estuary plants, a few very distinct species which grow only on the flats of rivers where twice a day the incoming tide pushes back the fresh or but slightly brackish waters. Only a few species can tolerate the rapid changes from drowning and immersion in mud and silt, alternating with drying off or toasting in the sunshine. Consequently the distinctive estuary species are a restricted and biologically significant group. The finest estuary in our region is that of the St. Lawrence, from slightly below Montreal to many miles below Quebec; others of note are the estuaries of the Penobscot, the Kennebec-Androscoggin system, the Merrimac, the Hudson, the Delaware, and Chesapeake Bay. Twenty years ago any of these estuaries would yield abundant material of their endemic (or epibiotic) species. But Montreal became a great fresh-water port for trans-Atlantic liners. Straw and litter from Europe thrown into the St. Lawrence quickly found lodgment, and the seeds or tubers of meadow plants of England and France discovered a new home. Today for many miles, from above Montreal to below Quebec, the formerly unique and endemic flora of the estuary is being rapidly

obliterated by the crowding and handsome but overwhelming flowering rush (*Butomus umbellatus*) and the purple loosestrife (*Lythrum Salicaria*), both gorgeous to look upon but unscrupulous and without mercy for the insignificant endemics, which cannot last many years longer. Similarly, on the lower Merrimac the same purple loosestrife, a joy to the artistic and unscientific eye, has obliterated the fastidious and localized endemics, which had become isolated there since the last withdrawal of the Champlain sea.

Unfortunately, these vagrant, aggressive, and opportunist weeds from Europe are destined to be the cosmopolitan flora of temperate regions as soon as man has a little further interfered with the natural habitats of our long-established native floras. They are our thoroughly successful wild plants, and their success is to be compared with that of the European man, the European rat, the European mouse, the European house (or "English") sparrow, the European starling, the European gypsy moth, the European brown-tail moth, the European house fly, and other invaders which, wherever they can get an opening, are rapidly replacing our indigenous Indians, rodents, birds, and insects which had long ago established an equilibrium.

In our native flora, likewise, there is a group of aggressive invaders, certain plastic and pioneering species which, along with the vagrants of European origin, often take possession of newly cleared and disturbed land: Pasture brake, flyaway grass (*Agrostis scabra*), aspen (*Populus tremuloides*), gray birch (*Betula populifolia*), hardhack (*Spiraea tomentosa*), wild strawberry, raspberry, blackberries, bird cherry, yellow ladies'-sorrel (*Oxalis europaea*), poison ivy, fireweed, pennyroyal, horseweed, and a hundred more. These are our native invaders but they are relatively harmless. They have been longer on the ground and, although showing some of the unrepressed traits of aggressive youth, they are surely less obnoxious in their behavior than are many of the recently arrived European invaders.

Then there are the dominant but unaggressive species, abundant over vast areas but showing little or no tendency to push in where they are not wanted: Cinnamon fern, various club mosses, ground yew, Indian poke, bayberry, hazel, beech, common clematis, columbine, sugar maple, and hundreds of others. These are the common species of appropriate wild habitats, the backbone of our flora, the bourgeois, vigorous, fertile, dependable, chiefly of late Tertiary dispersal and eminently respectable.

After them I should place the quiescent species, locally abundant over large areas, absent from equally extensive areas: Maidenhair fern, adder's-tongue fern, shagbark hickory, marsh marigold, bloodroot, climbing bittersweet, wicopy or leatherwood, ginseng, bottle gentians, fringed gentian, and three or four hundred others. These

are the plants familiar to everyone in certain areas, quite unknown in other areas, conservative as to habitat, holding their own and prospering under the conditions they have always known. Following the social classification adopted, they might be called the upper middle class, too fastidious to be "go-getters" but with enough vitality and reproductive capacity to prosper where conditions are favorable. This conservative but prospering element in the flora consists largely of genera or subgenera which have the interrupted eastern Asiatic-eastern American range. Whenever fossils of these groups—*Adiantum*, *Chamaecyparis*, *Carya* (hickory), the hornbeams, the black birches, *Celastrus*, *Tilia*, etc.—have been found they indicate a general occurrence in Tertiary time (sometimes Cretaceous) over the Northern Hemisphere, often including areas which are now the Arctic. It is significant, therefore, that these plants of considerable antiquity have largely lost the pioneering capacity of younger types.

Then come the various groups of local species, plants of wide general range but always with restricted areas, not abundant over large tracts: *Isotria affinis*, the small whorled pogonia, *Cypripedium arietinum*, the ram's-head lady's slipper, *Trollius laxus*, globe flower, *Polygala brevifolia*, *Polemonium Van-Bruntiæ* and many more. *Isotria affinis* (pl. 1, fig. 2) has altogether about a dozen known eastern stations, scattered from Virginia to Maine. Its northern outliers are a patch of 35 plants in Oxford County, Maine, one of a few individuals in central New Hampshire, and one of a single individual in northwestern Vermont. These plants are exclusive, undemocratic as to their associates, and show the social isolation and the limited reproduction of the aristocracy.

My chief concern today, however, is not with the ultrademocratic intruders from Europe or the bourgeois, the upper middle class, or even the lesser aristocrats in our indigenous flora. My plea is for wholehearted protection of that helpless but tremendously interesting group which may be called the fugitive aristrocrats, the completely isolated and usually entirely overlooked small colonies, doing no one any harm but of utmost importance to the student of life and its history through the last 100,000,000 years. Benjamin Franklin was himself a democrat, but *Franklinia*, named in his honor, was a fugitive aristocrat. Even if we try to overlook the commercial implication of Moses Marshall's last visit to the refuge of *Franklinia* on the Altamaha, it is perfectly evident that the unrestrained pressure of bourgeois and vagrant species about it and the unintelligent intrusion of aggressive man would soon have wiped it out. Its fate has been that of hundreds (no one can guess how many) of relict species, and a similar fate threatens the whole series of highly localized rarities.

The limestone ledges of Rock Island at the falls of the Ohio near Louisville, Ky., and New Albany, Ind., were, a century ago, the home of a remarkable number of highly localized plants. At least two of them have never been found elsewhere. One was *Psoralea stipulata* (pl. 2, fig. 1), the other *Solidago Shortii*. Each is a unique species, the *Psoralea* so peculiar that our most intensive student of the group has doubted [5] whether it is a *Psoralea* at all or whether it may belong to a wholly different tribe. The solution depends upon securing fruit of the plant, which is now out of the question. "Rock Island * * * was blasted away some years ago when the Ohio was made more navigable." As to *Solidago Shortii*, the layman would say "What of it? It is merely another goldenrod of which there are already too many." But consider a moment. When Edison started his studies of new sources of rubber he had as botanical adviser the late Dr. John K. Small. Shortly before his death Small told me that, of the hundreds of species of quickly growing plants which might serve, *Solidago Gattingeri* had been found to give the greatest yield of rubber. To the layman, again, *Solidago Gattingeri* is merely another goldenrod; to the economist it is a most promising quickly grown source of rubber; to the student of the flora it is a highly localized plant of a few limestone glades and knobs of Tennessee and adjacent Missouri. Luckily for the future of the rubber industry this goldenrod had not been exterminated before its economic importance was discovered! Incidentally, where would man and his civilization be today had not our "primitive" peoples of the past rescued, before their extermination in the wild state, such seemingly indispensable cereals as wheat and maize (Indian corn)? Who, in our present rudimentary state of intelligence, can predict what rare, localized, and usually overlooked species has economic possibilities?

Instances of the destruction of the last or only living colonies of other rare plants by the blasting away of ledges or the building of dams will occur to every experienced field botanist; and the pollution of rivers by strong chemicals from pulp mills and factories has been as fatal to the native flora of river gravels as to the salmon, shad, and other important fishes of the river channels. Some of the most amazing of plants grow only near rivers. On the upper St. John, between Maine and New Brunswick, there is a unique species of wood betony, *Pedicularis Furbishiae* (pl. 2, fig. 2), named for its discoverer, Kate Furbish. Under the manufactured English name, "Miss Furbish's lousewort," it does not sound very interesting. Its only close relative, however, is on the other side of the world, in the mountains near Lake Baikal in southern Siberia. It is, then, one of the most telling evidences that life on the upper St. John was not wholly

[5] See Rydberg, Torreya, vol. 26, p. 89, 1926.

destroyed, as we were taught, by Pleistocene ice. To the student of biogeography it is a most important plant. Luckily, no factories, vomiting poison into the river, have yet been built upriver from it. Let them once start to pollute the waters and then develop a freshet to overflow the banks; immediately the last plant of *Pedicularis Furbishiae* will die and this living witness to the past wide dispersal of its group will be gone.

Another danger to plants of river gravels is the mechanical one of log driving. In 1905, on one of the Gaspé rivers, my companion and I found, among other extraordinary plants, a half-shrubby strawberry, *Fragaria multicipita* (pl. 3), with many erect long-lived fruiting branches but no slender runners, such as a conventional strawberry plant should have. It is not closely related to any known species. Near it was a single small colony of an equally remarkable willow, *Salix obtusata*, a shrub which the great monographer of the willows, Dr. Camillo Schneider, can relate to no living species. Twenty years later, taking a party of botanists to see these two unique plants, we found that the heavy teaming of a logging crew and the use of the beach as a lumber camp had quite extinguished them. None but the botanist mourns the loss of these species; their burial ground is now covered with aggressive weeds of European origin brought there by the lumber crew.

Another notable plant, partly destroyed by the activity of man, aided perhaps by nature, is the handsome mallow, *Phymosia* (or *Sphaeralcea*) *remota* (pl. 4, fig. 1), related only to plants a thousand miles or more away. Originally known only from a gravelly island in the Kankakee in Illinois, the species suffered from its distinguished beauty and its shifting habitat and there eventually became nearly extinct. In 1927 a second station for it was found more than 450 miles to the southeast, in western Virginia, a region originally rich in these highly localized species. In the Virginia habitat "the individual specimens grow vigorously and attain a height of 6 feet or more. * * * Although there is an abundant supply of seeds each year, reproduction seems to be at a low ebb for there is apparently no spread of the plants and the number during the years from 1927 to 1931 has remained fairly constant, the total number at the present time being not more than 50." To be sure, brought into the garden and given artificial aid in germinating, the plant succeeds. But in its natural habitat, which alone interests the student of historical phytogeography, it is constantly in danger of a raid by some overzealous and commercially minded seeker for rare plants for the garden.

Among the most remarkable descendants of the ancient flora which once girdled the whole northern hemisphere, is the beautiful yellow-flowered shrub, *Kerria japonica*, brought from eastern Asia to our

gardens. But *Kerria* has a very close ally lingering at the southern margin of the Appalachian Upland. At a few spots near Tuscaloosa, Ala., *Neviusia alabamensis* (pl. 4, fig. 2), like an apetalous *Kerria*, occurs, discovered in 1858. It is a dramatically interesting and biologically most significant plant; and no one has ever found it in adjacent States. Let an impulse to blast away the cliffs where it grows lead to fatal action, some one may become momentarily richer thereby but *Neviusia* will be gone. In 1934 Bayard Long and I found a singular plant in a very restricted bit of peat near large fresh-water ponds in Princess Anne County, Va. Unlike anything known to us, it eventually proved to be a member of *Hypoxis*, subgenus *Ianthe*, of the Australian region and South Africa. One other member of *Ianthe* occurs as one of the very rarest of plants in the southeastern States. Otherwise the group belongs in the antipodes. To the botanist the little colony of *Hypoxis Longii* in Princess Anne County is of great significance, as one of the living descendants of the flora of Cretaceous dispersal which reached Australia before it was cut off from connection with other lands. It was discovered in 1934; it prospered in 1935; but in 1936 word came to me that the neighboring ponds were being drained and the *Hypoxis* area ditched. Fortunately the little *Hypoxis* is still holding on; but it is inevitable that the time will come, with the "improvements" now going on, when it must completely disappear. In fact, deep ditching and consequent lowering of the water table, such as the powers that be have extensively carried forward on the Atlantic Coastal Plain, spells ruination to the highly specialized and sensitive descendants of ancient stocks which, undisturbed, have been able, until the advent of the white man, to hold on in specially favorable spots. Incidentally it is ruining the breeding and feeding haunts of the vast group of organisms, both animal and vegetable, which have always lived together and depended upon one another. Recent pages of journals devoted to the saving of natural conditions are replete with such facts.

Strongly suggesting the geographic relationships of *Hypoxis*, subgenus *Ianthe*, are many other pantropical groups represented on our Atlantic Coastal Plain. As thrilling as any are the *Burmanniaceae*, tiny plants of a family closely related to the orchids. *Burmannia biflora* was based by Linnaeus upon three specimens collected by Clayton in Virginia. Except for material said to have been obtained by Thomas Nuttall somewhere in the State more than a century ago, we have known of no other collections since Clayton's until the recent discovery of four stations for it, two in Greensville County, one in Southampton, one in Nansemond. At its really extensive station in Greensville County it is in a sphagnous bog still persisting at the margin of a cultivated field. *Burmannia* there nestles in the shade

of *Lachnocaulon anceps* and *Rhexia ciliosa*, and its associates are as notable a group of pine-barren and bog species as any in Virginia. Among them are the two characteristic and highly localized species of *Utricularia:* the tropical *U. juncea*, with conspicuous yellow flowers, and the very rare smaller-flowered imitation of it, *U. virgatula.* Here is the northernmost known station for the remarkable *Oxypolis ternata* (pl. 5, fig. 1). Although originally described by Nuttall as coming from "bushy margins of swamps, in the pine forests of North and South Carolina," the plant is so very local that in 1900 Coulter and Rose were able to cite specimens of it only from Apalachicola! There are perhaps 25 plants in the Greensville County bog. Near them there occurs a colony, about 1 rod in diameter, of the excessively rare *Calamovilfa brevipilis.*

Typical *Calamovilfa brevipilis* is confined to the pine barrens of New Jersey. In southeastern North Carolina there is a very rare plant resembling the New Jersey series, but with characters of the spikelet setting it apart as a distinct geographic variety. We know it from only a single station. The plant of Greensville County, occupying 1 square rod of bog, is an extreme departure in its flowering parts from both the others. In their bases and vegetative characters the three really distinct plants are inseparable, but the details of their spikelets are so different as to mark three highly localized varieties of one ancient type.

As another member of this remarkable assemblage which has not yet wholly gone under the plow I will mention *Zigadenus angustifolius* or *Amianthium angustifolium.* Occurring on the Coastal Plain from eastern Louisiana to Florida, thence to southeastern Virginia, the plant has relict colonies on the ancient Appalachian core of eastern North America. It is an ancient type still persisting. Originally put into *Helonias*, the species has been placed at times in *Amianthium*, at times in *Zigadenus.* It is atypical in any of them, and Small constitutes of it a genus by itself, *Tracyanthus.* Whether it belongs to a new or an old genus, the species is obviously old. So far as we yet know there is a solitary small colony of it in Virginia.

The bog where these plants still persisted in Virginia in October 1938 was discovered in the preceding July. In August it was intact; in September it had been invaded by hogs. In April 1939 a band 20 feet wide had been plowed at the upper margin, but in July it was noticed that the newly plowed land had yielded no crop except corn 8 or 10 inches high. For agricultural purposes the soggy, acid land is absolutely useless, but the plowing has now been done. A broad strip of *Burmannia biflora* and its very rare associates is ruined. Weedy types will now occupy the 20-foot belt where they formerly grew.

The persistence of *Zigadenus angustifolius* at spots on the ancient Appalachian Upland suggests many other plants of similar Coastal Plain and upland or montane occurrence. *Parnassia asarifolia*, primarily a species of bogs along the mountains of western Virginia and the Carolinas, occurs in at least one springy bog in Tidewater Virginia. Within a few rods of it there is a fine colony of *Helonias bullata*, a montane plant of western Virginia and North Carolina, a local Coastal Plain plant from eastern Virginia to Long Island. Among their companions, in this case in eastern Henrico County, are *Juncus caesariensis*, which, until Grimes got it near Williamsburg, was looked upon as an endemic of southern New Jersey, and typical *Solidago Elliottii* which, according to Mackenzie (in Small's Manual) has been known only from Parris Island in southeastern South Carolina. Not far away, in Whiteoak Swamp, *Styrax americana* reaches its northern limit and the little-known *Thalictrum macrostylum* abounds. *Carex Collinsii*, always an interesting plant, is in the thicket near *Helonias;* and *Xyris platylepis*, a beautiful southern species with large castaneous bulbs, abounds. These are only a few of the specialties of these springy and boggy slopes. Most happily, they are along the right-of-way of a great railroad and are unlikely to be invaded by hogs, cattle, and plows.

In Sussex County, Va., there is an extensive area most difficult to define. In June it is a soaking-wet quagmire which has some traits of a sphagnous bog, others suggesting a savanna, but with more or less open pine woods. In August it is a sun-baked and exsiccated argillaceous woodland; in October we called it a damp pineland. The flora is as difficult to classify. In June it is a solid swale of *Juncus Elliottii* (Coastal Plain from Texas to Florida, thence north to eastern Virginia, with a local station in Delaware and a single one in Coffee County, Tenn.), mingled with *Carex Barrattii* (Connecticut to Maryland; isolated in southeastern Virginia and in southern North Carolina, with rare upland stations in Tennessee and Alabama), *Carex Buxbaumii* (northern Eurasia; Greenland to British Columbia, south, very rarely to Delaware and the District of Columbia and at one station in North Carolina). Those are the significant plants in mid-June. In August one specialty prevails, *Manisuris rugosa*, the northernmost member of a tropical genus. Returning in October one will find the wet pineland covered with a very unusual closed gentian with linear-lanceolate leaves and azure-blue flowers striped with a darker blue. Unlike anything heretofore recognized in Virginia, it proves to be a close match for an isotype of the "Cherokee gentian," *Gentiana cherokeensis* (pl. 5, fig. 2), described in 1935 from the mountains of northwestern Georgia, the name given to the species, to use its author's words, "because apparently restricted to the terri-

tory anciently occupied by the Cherokee Indians." The "Cherokee gentian" is now likewise known in the ancient land of the Powhatan.

The white sandy pinelands and barrens of southeastern Southampton County, Va., are the northern limit for many rare southern species. Here was a colony of *Physalis monticola*, the first one known outside northeastern Alabama, whence Carl Mohr described it from the tableland of Lookout Mountain in DeKalb County. The isolation of *Physalis monticola* on the Coastal Plain of Virginia at once recalls the "Cherokee gentian," just discussed. The latter has a real stronghold in Virginia; but someone, thinking to raise crops in the white sand of southeastern Southampton, cleared and plowed a patch of it, thus destroying all but a few roots of the *Physalis*. The crop raised was like that at the margin of the *Burmannia* bog, Indian corn 6 to 10 inches high, but here freely interspersed with dismembered and gloriously sprouting prickly pears. *Physalis monticola*, a real rarity, is almost destroyed; the prickly pears have been vastly multiplied; the crop of Indian corn came to nothing. But the harm has been done and vagrant weeds, with *Opuntia*, will now occupy the area.

Only a few colonies (and these varying from a single individual to a dozen or two scattered plants) are known in Tidewater Virginia of the rare orchid, *Cleistes* (or *Pogonia*) *divaricata* (pl. 6, fig. 1), the largest-flowered orchid north of the subtropical areas. Altogether too many people for the good of the plant are aware of its largest station. In September 1937, a small colony was found within 2 rods of the Petersburg-Suffolk highway. But it is necessary that our automobiles go faster and without delay if we are to keep up the hectic pace of so-called civilization. Moderation and calm are out of fashion, and no mere plant, however interesting, should retard the pace. The Wakefield colony of *Cleistes divaricata* is now closely crowded by the soft shoulder of the new lane of the trunk road to Suffolk. It will not long tolerate flying clots of tar and oil and the gradual slipping down of wastage from the soft shoulder. Only two persons know the colony; and they are mere botanists.

Another instance where modern road construction has threatened—in this case exterminated—a rare plant is that of the American lotus or water chinquapin (*Nelumbo*) on Cape Cod. One of the two native colonies of *Nelumbo* (pl. 6, fig. 2) along the Atlantic slope north of the local stations in New Jersey was a muddy pond-hole near Mashpee, on Cape Cod. But the summer visitors who throng Cape Cod to enjoy its unspoiled native simplicity must have more trunk roads, and the single native Massachusetts station for *Nelumbo* is now an up-to-date stretch of concrete.

As a last illustration of what science has lost and is helplessly losing I will mention a little wintergreen whose ancient home has literally become a graveyard. Throughout the vast order *Ericales* or heaths, a world-wide group, the anthers are erect, except in *Pyrola* and its allies. In this group, differing from the others in its herbaceous instead of woody habit, the anthers in bud are erect and extrorse (opening outward) but in the opening flower they become inverted so that their morphologically basal pores are at the top, the morphologically uppermost points at the bottom, and their dehiscence is introrse instead of extrorse. All over the Northern Hemisphere *Pyrola* is consistent in reversing the direction of its anthers; but, apparently, it used to have them as in the ancient woody heaths. In 1860 the late Coe F. Austin discovered on a wooded slope in the Delaware Valley a most amazing *Pyrola*, which he described as *P. oxypetala*. In leaves and petals it is unlike other species of the genus but, strangest of all, it has the mature anthers erect. Unfortunately, this remarkable and only known link between modern *Pyrola* and the ancient heaths has never been rediscovered; but fortunately, Dr. Austin preserved good material of it. Many botanists have sought it, and I have personally had a try for it. The locality best fitting Austin's account is now a suburban cemetery, with carefully scraped and groomed banks and landscaped effects, with everything possible done to discourage a native plant or animal of fastidious habits and specialized requirements.[6] The people of the neighboring city do not care; they never heard of *Pyrola oxypetala*. It has nothing to do with their lives, and where it originally grew they have a conventionalized or standardized area in which to lie after their earthly careers are finished. *Pyrola oxypetala* would have seemed an insignificant "weed" to the landscape architect who wanted foreign plants put in its place.

Right here is the most serious problem for those who regret the unnecessary destruction of our sensitive and retiring species of plants and animals. For it has been too much the custom to overlook the fact that the oldest and most interesting of animals and plants are what I have called the fugitive aristocrats. These are the rare and ecologically most retiring and specialized species, known only to a few special students of a region; and anything which upsets the equilibrium to which, through millions and millions of years, they have gradually become adjusted, is fatal to them. If the experienced botanist were first consulted, no conventional planner of man-made landscape and unintentional destroyer of these inconspicuous

[6] In the case of *Pyrola*, dependence on mycorrhiza.

relict species and of nature's equilibrium would have a place on any board which is to control the destinies of preserves for wild life. When I first knew eastern Massachusetts, many public-spirited citizens gave freely to the State wild forest lands for State reservations which were to be kept forever wild. The project was put into the hands of a commission, with a distinguished landscape architect at its head. To the commission the maintenance of wild, natural conditions was indeed a "project." Original donors of land and lovers of nature protested in vain. Undershrubs were cleared out, destroying the nesting haunts of various native birds; the dead leaves, which supply the humus for many rare plants and the hiding places of many small animals, were raked up; and everything unwittingly done to make the areas forbidding to sensitive and retiring species.

Naturally, we cannot expect all so-called human progress to be held up because nature is in the way. Man's mastery over nature is one of his proudest boasts. The highly trained and often overcultured landscapist is in one respect only a step removed from the unschooled French-Canadian habitant. The latter will cut down, with almost religious fervor, his enemy, the native forest; then, almost instantly, he will plant foreign trees and shrubs about his church and home! So long as man has the passion to alter the perfectly balanced conditions of life which nature, through countless ages, has developed, the rare and retiring plant or animal has no more chance of survival than has the human fugitive aristocrat in the dictator-ruled countries which are so upsetting to lovers of human liberty. Let the conventionalizer of landscape confine his useful art to areas which may appropriately be conventionalized and where nature is admittedly "conquered" by man.

The plights of the bison, the prairie hen, the Labrador duck, the passenger pigeon, the great auk, and scores of other birds and mammals are familiar. Our last refuge of the great auk or penguin was Funk Island, off the coast of Newfoundland. There it was far from settlements; but Nordic fishermen, realizing the wickedness of fishing on the Sabbath, spent their Sundays on Funk Island and gave exercise to their fervor by clubbing to death the last remnants of these ancient and primitive birds. This wicked slaughter can in no way be attributed to their resentment that Anatole France in Penguin Island had ascribed human attributes and human souls to these dignified birds. The slaughter was finished before the publication of Penguin Island.

In the well-meant enthusiasm to "do something," altogether too many of the restricted spots which still retain some elements of the original life bequeathed to us from the past are being converted into artificial and man-made tracts. Rare and relatively inconspicuous

plants are destroyed to make way for conspicuous foreigners, artificial ponds are constructed, modest wood paths are altered to concrete roads, that the public may speed rapidly through the intended beauty spot, where, under the now popular but often misinterpreted slogan "conservation," man has done his best to make the face of nature unnatural.

Think carefully for a moment. The building of artificial ponds, roads, artificial bridges, and artificial beaches, and the planting of introduced trees and shrubs is not conservation. It is just the opposite of true conservation, for it upsets the natural equilibrium which had become established long before man, proud of a supposed resemblance to God, came to ruin it. True conservation[7] leaves nature, mother of us all, uninjured and the true conservationist is a lover and defender of uninjured nature.

If groups of otherwise unemployed young men are to be encouraged to hew, rake, and alter areas set aside as natural preserves, they will unconsciously become destroyers of the natural equilibrium of nature. Put them to work destroying the vagrant pests which crowd us and which are a worthy foe. Our open lots and roadsides are overrun with ragweed, the most prolific cause of hay fever, as well as by poison ivy, tent caterpillars and scores of other nuisances. No one really cherishes ragweed; but it is a formidable task for a few individuals to clear it all up. It is a quick-growing annual and by concerted action its eradication, or the reduction of poison ivy or of tent caterpillars would be accomplished. Or consider the Japanese honeysuckle (pl. 7). So long as it is kept in restraint this Asiatic migrant is a handsome vine; but it has invaded the Southeast like a horde of Huns. Everywhere from the Gulf States to Long Island this rampant and unrestrained foreign twiner is strangling the native vegetation and producing a monotonous landscape in place of the diversified landscape of many native species which nature bequeathed us. It has become what I have elsewhere called the yellow peril of the South. Its destruction would be a notable achievement. Its continued toleration is a menace to the native plants and animals.

[7] In view of the evident misinterpretation of the meaning of "conservation," as evidenced by numerous comments in papers and magazines and in scores of personal letters received by the writer since the delivery of this paper, it is well to quote from the Century Dictionary:

"**conservation** . . . [. . . L. *conservatio* (*n*—), < *conservare*, pp. *conservatus*, keep: see *conserve*, *v*.] 1. The act of conserving, guarding, or keeping with care; preservation from loss, decay, injury, or violation; the keeping of a thing in a safe or entire state."

"**conserve** . . . 1. To keep in a safe or sound state; save; preserve from loss, decay, waste, or injury; defend from violation: as, to *conserve* bodies from perishing."

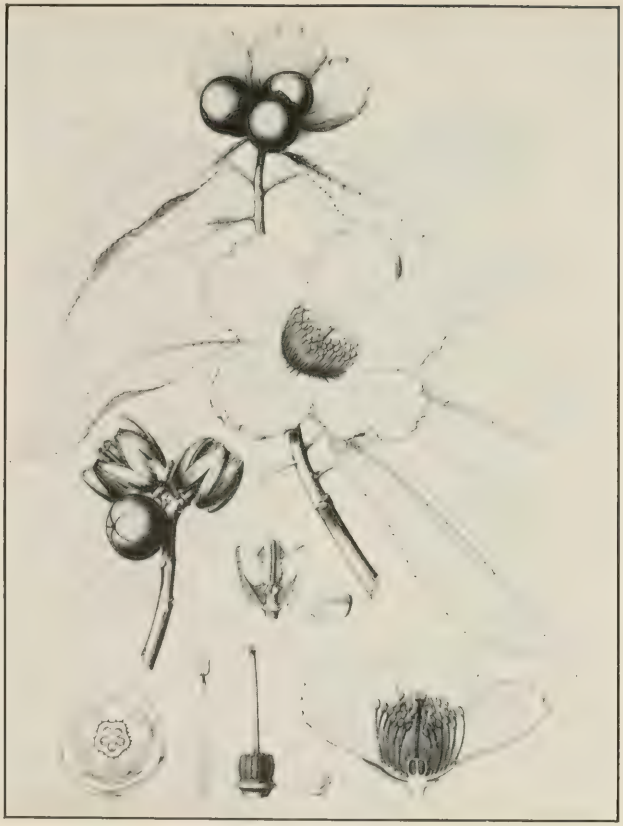
As soon as man, or his implements, disturbs the long-established interrelation of organisms in the wild, he innocently but nevertheless effectively prevents the *conservation* of these delicately interrelated animals and plants. In the brief space available this important question can hardly be expanded. The spread of youthful and aggressive "weeds" already referred to and the destruction of the feeding grounds of shore birds are pertinent illustrations.

I have preached enough. The problem is most difficult. The country is awakening, we hope, to a belated appreciation of its precious birthright, now largely wasted. Lovers of birds and mammals have made the right start. Lovers of the rare and scientifically most significant plants urge that all rare native species be given a real chance.

The few out of thousands of instances of destruction of or imminent threat to our rarest and often choicest native plants above noted are unfortunately wholly typical. The problems are not merely for Virginia or Maine or Quebec. They concern us all. The layman and the practical developer of roads, farms, clearings, deep-ditching, and draining of ponds and swamps know nothing of them and, if they did, it is not probable that they would consider the conservation of a few rare plants as counterbalancing the more "practical" demands of so-called progress. When nature is in the way it seems, as already noted, to be man's passion to conquer her. From earliest times his two proudest boasts have been his mastery over nature and his resemblance to God, who must often be ashamed of the resemblance. I have heard self-styled sportsmen in Virginia argue against protection of ducks and other shore birds, saying: "God made them for us to kill; why shouldn't we do what he wanted us to do?" If this is the correct doctrine, then we should make all haste to kill the shore birds and with them the rarest of plants. Might it not be better, however, to take the opposite line of reasoning? If God (working through unhampered nature) preserved the rarer and biologically often the most significant of plants and animals until the Nordics came to America to kill them out, is it not clear that their complete destruction was not a part of the original scheme? The extermination of many of them has already been complete. Isolated and tiny colonies of others still occasionally persist. It is surely the part of wisdom and of consideration for our descendents for our boasted civilization to see that something besides the commonplace and the economically immediately useful is left in our flora and fauna for them to study and enjoy. In sympathetically preserved large tracts, like some of the national parks, this is possible, and in some of them the obligation is, happily, recognized. Furthermore, on the splendid old plantations along the James and other southern rivers many unspoiled tracts of woodland and marsh are preserving their native plants intact. But is there any hope for the small and isolated pockets here and there amidst cultivated fields and pig and cow pastures? I introduce the question. Let us all think, and think hard, until some wise solution of the problem is found.

The words of the sixteenth century herbalist addressed to his patron, "the right Honorable his singular good Lord and Master, Sir William Cecil Knight," conveyed in the stilted and elegant style of the period the healthy attitude:

> Among the manifold creatures of God (right Honorable, and my singular good Lord) that have all in all ages diversly entertained many excellent wits, and drawne them to the contemplation of the divine wisdome, none have provoked mens studies more, or satisfied their desires so much as Plants have done, and that upon just and worthy causes: For if delight may provoke mens labor, what greater delight is there than to behold the earth apparrelled with plants, as with a robe of embroidered worke, set with Orient pearles, and garnished with great diuersitie of rare and costly iewels? If this varietie and perfection of colours may affect the eye, it is such in herbs and flowres, that no *Apelles*, no *Zeuxis* euer could by any art expresse the like: if odours or if taste may worke satisfaction, they are both so soueraigne in plants, and so comfortabel, that no confection of the Apothecaries can equall their excellent vertue. But these delights are in the outward sences: the principall delight is in the minde, singularly enriched with the knowledge of these visible things, setting forth to vs the inuisible wisedome and admirable workmanship of almighty God.



1. FRANKLINIA ALTAMAHA (GORDONIA ALTAMAHA), FRANKLINIA.

Exterminated as a native tree in 1790. From the plate in Sargent's Sylva of North America. (Houghton-Mifflin Co.)



2. ISOTRIA AFFINIS.

Small-whorled Pogonia, known at only a dozen small stations from Virginia to Maine. Promptly killed out by destruction of woodland humus.



1. PSORALEA STIPULATA.

Never known except on limestone rocks at the Falls of the Ohio. Destroyed by blasting away of the ledges. Its true botanical relationship can be determined only through its fruit, which will never be known.



2. PEDICULARIS FURBISHIAE (MISS FURBISH'S WOOD BETONY).

Known only on the wooded and ledgy shores of the upper St. John River, between northern Maine and northwestern New Brunswick. Pollution of the upper St. John by inimical chemicals and spread of them by a freshet might kill out the only American species of the group.



FRAGARIA MULTICIPITA (MANY-CROWNED STRAWBERRY)

A peculiar half-shrubby strawberry, discovered in 1905 in the gravel of one of the Gaspé rivers. Probably destroyed by subsequent heavy teaming and other routine of a logging crew who occupied the beach as a lumber camp.



1. PHYMOSIA (OR SPHAERALCEA) REMOTA.

An ornamental species, known only from an island in the Kankakee River, Ill., where it is now nearly extinct, and a mountain slope in western Virginia. A raid on its two restricted stations would finish its existence as a native plant.



2. NEVIUSIA ALABAMENSIS (NEVIUSIA).

The only member of the genus, closely related to *Kerria* of Japan and China. Growing locally near Tuscaloosa, Ala. Blasting away of the cliffs and bluffs where it grows would soon obliterate this witness to the antiquity of living plants.



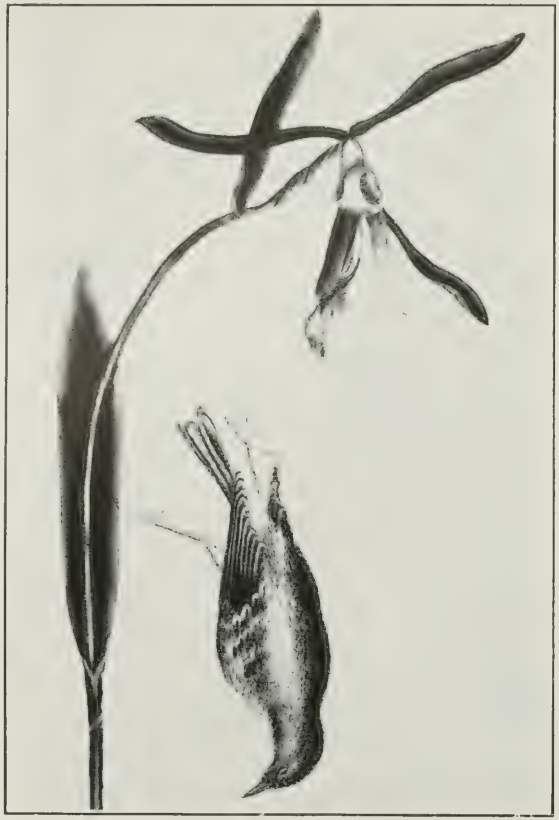
1. OXYPOLIS TERNATA.

A small member of the parsnip group, always very local and known only in a few peaty or mossy pinelands. Its northernmost colony, where it grows with *Burmannia* and other rare plants, is already invaded by the plow.



2. GENTIANA CHEROKEENSIS. CHEROKEE GENTIAN.

A beautiful gentian known only from the mountains of northwestern Georgia and from a wet pineland in Sussex County, Va. Burning of the pineland would ruin the only known station outside Georgia.



1. CLEISTES DIVARICATA (ROSE ORCHID).

Our largest-flowered terrestrial orchid, found very rarely in bogs and pinelands at the northern borders of its range. Road making and other activities are seriously encroaching upon it. The photograph is copied from one of the remarkable colored plates of Catesby, two centuries ago.



2. NELUMBO LUTEA (AMERICAN LOTUS OR WATER CHINQUAPIN).

Abundant in some areas in the southeastern and central States. The only native colony in Massachusetts was obliterated by road making. From an old plate in Curtis's Botanical Magazine.



LONICERA JAPONICA (JAPANESE HONEYSUCKLE).

It has invaded the Southeast like a horde of Huns. Everywhere from the Gulf States to Long Island this rampant and unrestrained foreign twiner is strangling the native vegetation and producing a monotonous landscape. Its continued toleration is a menace to the native plants and animals.

PLANKTON IN THE WATER SUPPLY

By Florence E. Meier

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[With 11 plates]

INTRODUCTION

"It is good to keep water in copper vessels, to expose to sunlight and to filter through charcoal," are the words of an ancient Sanskrit author written in 800 B. C., more than 27 centuries ago. Water has been a necessity since the beginning of life, and the problem of obtaining pure water free from disease germs has increased in magnitude with the complex growth of civilization and the crowding of people into towns and cities. The importance of a good water supply has long been recognized, as testified by Caesar's aqueducts, but the importance of a standard of purity in drinking water is more recently indicated by the statistics showing the decrease in death rates of cities, a decrease due to the elimination of water-borne disease germs from city water supplies.

Nature is abundant in her gift of water, but since water is the home of countless living organisms, many of them harmless, others directly injurious to man, it is essential to determine means for their elimination in order to insure a satisfactory domestic water supply.

In medieval times the smaller populations caused comparatively little contamination of the water. When epidemics of dysentery and typhoid fever did occur, owing to pollution of the water, they were accepted more or less as a matter of course. Our ancestors would be amazed at the science of modern waterworks, involving engineering, bacteriology, biology, and chemistry, which has been developed to ascertain water purity. Very often an expensive installation that has been constructed for the storage and delivery of water serves its purpose for a time, but then the quality of the water deteriorates or the supply dwindles or even abruptly ceases. The installation set up by man, instead of preventing, may propagate the microorganisms in the water that cause spoiling of the water or interference with its flow.

Because of the extent of water-borne diseases caused by the gradual increase in stream pollution and the necessity of utilizing polluted streams as sources of public water supply, it was found necessary at an early period in our history to place the responsibility in the State and city boards of health for the inspection and supervision of watersheds to prevent further pollution of water supplies.

EARLY HISTORY OF MICROSCOPICAL EXAMINATION OF WATER

The first written record that called attention to the necessity of water-supply control was an anonymous pamphlet published in London in 1827 under the title: "The Dolphin; or Grand Junction Nuisance: Proving that Seven Thousand Families in Westminster and its Suburbs are Supplied with Water in a State, Offensive to the Sight, Disgusting to the imagination, and Destructive to Health." A view of the left bank of the Thames River at Chelsea was depicted and in the foreground was a "dolphin," a small wooden Martello-tower-like construction rising from the water a few yards from the shore and marking the site below water of the intake pipe of the Grand Junction Water Co. In the background were shown Chelsea Hospital and the pumping works of the company, separated by the great Ranelagh sewer, whence a flood of sewage poured into the river abreast of, and within about 3 yards of, the dolphin. The author sent samples of the water, just as it came from the company's pipes into his house cistern, to several eminent doctors.

One of these doctors replied to the author giving a description of his tap water as follows: "Scarcely a week passes that I am not presented with a leech; a shrimp-like skipping insect nearly an inch in length; a small red delicate worm, which I believe is *lumbricus fluviatilis* or some other animalcula; and the water is most opaline, muddy, or otherwise impure."

In 1829 James Simpson set up the first working sand-filter in London.

It was not until 1850, however, that the first adequate account of a thorough microscopical examination of any water supply was published by Dr. Hassall in London. This was followed by MacDonald's work entitled: "Guide to the Examination of Drinking Water." In the meantime various Germans carried on research relating to the biology of water supplies; especially noteworthy is the contribution by Professor Cohn, of Breslau, under the title: "Microscopical Analysis of Waters," which anticipated later findings on the effect of environment on the character and quantity of organisms in drinking water. This paper was followed by others, by Farlow and numerous writers in the United States, on the presence of disagreeable odors and tastes in drinking water. By 1878, 60 cities and towns in the United States

had recorded serious trouble due to vegetation in their reservoirs. Since that time, thousands have recorded similar difficulties. To the Massachusetts State Board of Health belongs the credit for having begun as early as 1887 a systematic examination of all the water supplies in that State.

THE PLANKTON

The uninvited guests which cause so much difficulty in our water supplies are classed under the term plankton. In 1887 Hensen, of Germany, published a new method for studying the minute floating organisms found in lakes. He gave these organisms the name "plankton" from the Greek word "planktos," which means "wandering." Plankton includes the free-floating or weakly swimming organisms, algae and bacteria (minute plants), and protozoa (minute animals) that form an independent group in a body of water. Plankton rarely causes disease nor does it often spread organisms that do. The presence of plankton is generally made known in the water supply by the appearance, taste, or odor of the water and interference with the operation of the filter plant.

ALGAE

Algae (pls. 4, 5, 6) make up the largest number of the plankton in the water supply. They represent one of the lowest divisions of plant life and are characterized by the absence of roots, stems, leaves, flowers, and seeds. Some species are composed of single cells, which are microscopic in size; others consist of clumps of cells; and still others consist of numerous cells bound together in long threads or filaments, which are able to attach themselves to submerged objects. We are all familiar with algae that form the green scum of ditches and fish ponds and make a green coating on old stone walls and trees.

Algae have differences in pigment that serve as a basis for their classification although they all contain the green pigment, chlorophyll, even when it may be screened from view by another pigment. The *Chlorophyceae* are the true green algae, the *Cyanophyceae* are the blue-green, the *Phaeophyceae* are the brown, and the *Rhodophyceae*, the red algae. The two latter classes of algae consist mainly of the marine forms, therefore the *Chlorophyceae* and the *Cyanophyceae* are the two classes of algae occurring most frequently in our water supplies. The diatoms (pl. 3) often associated with the algae have a yellow pigment and a siliceous shell constructed like a pill box.

One important characteristic of the algae from the point of view of the waterworks engineer is their power of rapid multiplication, which enables great numbers to appear in a very short time provided environmental conditions are favorable. Their simplest

method of reproduction is for a single cell to divide into two cells. In the unicellular algae the two cells so formed separate at once; in multicellular forms, the cells remain attached to each other in arrangements that give the plants their characteristic spherical, filamentous, or leaflike shape. Rapid multiplication of the cells in a filamentous form, as in the blue-green algae, is often accompanied by the breaking up of the filament into short rodlike pieces, each of which forms a new filament. Other means of reproduction, both sexual and asexual, exist in the algae, in the process of which, special reproductive bodies unlike the parent cells are formed. The essential feature of their sexual reproduction consists in the fusion of two cells to form one. This is normally followed by vigorous new growth. In asexual reproduction one cell divides to form several bodies, which may grow into new plants without any fusion of the cells occurring.

Thick-walled resting spores are frequently formed. These cells can remain at rest for some time, often withstanding cold and dryness until favorable conditions arise for their germination. They increase greatly the power of the algae to maintain themselves in the waterworks, for they can be blown with the wind in the dust and be carried on the feet and feathers of birds from one body of water to another, and they can survive the emptying of reservoirs and the drying of reservoirs and filters.

BACTERIA

The bacteria (pl. 7, fig. 1; pl. 10, fig. 3), the tiniest of microscopic organisms to be found in the water supply, are of interest in that they may include the *Bacillus coli*. Pollution of the water introduces large numbers of bacteria of the colon group, usually harmless organisms when confined to the intestinal tract of man, but definitely pathogenic when liberated into the serous cavities of the body. The bacteria of this group are frequently found in the water supply in greater numbers and variety than the bacteria that produce diseases, such as those causing typhoid fever. The bacteria of the colon group are also more hardy than the disease-producing bacteria. Treated water, after filtration, should be examined daily for *Bacillus coli*. If the purified water is free from them, it is safe to assume that it will not contain the harmful bacteria, which are less resistant.

Crenothrix, one of the higher bacteria, is a microscopic threadlike organism closely related to true bacteria and fungi. It can live in the dark and in the absence of dissolved oxygen but does not thrive in water containing large quantities of dissolved oxygen. It requires iron as an essential food and so will live inside distribution systems that contain iron. It can grow on the inside of water

mains in gelatinous masses, which seriously reduce the caliber of the mains as well as causing objectionable tastes, odors, and precipitation of iron in the water. Its presence can ordinarily be assured when well water containing iron and little or no dissolved oxygen is pumped into the distribution mains.

ANIMAL FORMS

Microscopic animal forms flourish among the algae, since the two kinds of life are interdependent in the exchange of gases and other sources of their food supply. The animals consist chiefly of the one-celled Protozoa (pls. 8, 9), which occasionally cause trouble in the water supply. There are also Rotifera, which are common but not troublesome, Crustacea (pl. 7, fig. 3), which include the waterfleas, the Porifera or fresh-water sponges, the Bryozoa, and miscellaneous organisms such as worms and insect larvae.

FACTORS INFLUENCING PLANKTON GROWTH

Since algae are plants containing chlorophyll or green coloring matter, they are able to manufacture their own food. The most essential factor of their environment for carrying on the process of photosynthesis or food production is light. Turbid waters allow less light to penetrate, thereby decreasing the amount of algal growth. Ground waters do not permit algal growth unless exposed to light. For this reason, covered reservoirs are effective in algal control.

Temperature is another important factor in the environment of algae; it may either accelerate or retard their amount of growth. Some algae thrive beneath the ice, while other varieties prefer warm temperatures of 50° to 70° F. Although different kinds of algae grow at different seasons of the year and in different places, there is generally a spring maximum of diatoms, an early summer maximum of green algae, a late summer and early fall maximum of blue-green algae, and sometimes a second wave of diatoms in the fall.

Recurrences of plankton are not entirely due to temperature conditions. The physical conditions of the stream feeding the water supply may be responsible. The fluctuating levels of a stream, causing changing velocity and turbidity of the water, affect the numbers of the plankton. The velocity of the current is important, as rich growths of plankton are often completely destroyed by passing through a series of rapids or sharp falls.

Kofoid, after a 5-year study of the Illinois River, decided that the age of the water is an important factor in plankton production in streams. There is very little plankton in young streams. Barren waters impounded for 10 to 30 days develop a large plankton crop, which is affected by the rate of run-off and displacement, the plank-

ton being greatest where run-off and renewal are least. In other words, a swift stream allows little time for the production of plankton, whereas a sluggish stream affords greater time. The plankton productivity of a stream is proportional to the age of the water and inversely proportional to its velocity, as Reinhard also found in his study of the upper Mississippi River.

Inorganic elements are required for the growth of the algae just as they are essential for the growth of higher plants. In addition to water, carbon dioxide, oxygen, nitrates, sulfates, and phosphates are necessary parts of their food supply. The inorganic materials in solution in the water vary in kind and concentration according to the type of soil present in the drainage areas of the streams. Birge and Juday, in their extensive studies of Wisconsin lakes, reported that many soft-water lakes contain less plankton than the hard-water lakes. The growth rate is increased in the hard-water lakes by the presence of bicarbonates and greater amounts of carbon dioxide in the water. On the other hand, soft water and bog drainage promote the growth of some green algae. An excess of chlorides is also found where there is great production of algae. Although chlorides are not utilized directly by the algae, an excess of chlorides in the water usually indicates that the water contains a relatively large mass of fertilizing substances coming from sewage contamination. Small amounts of these fertilizing substances are beneficial for plankton growth. Minder, in his biochemical study of the Lake of Zurich, concluded that nitrogen in the form of nitrates is the principal factor that regulates the quantity of plankton. There is a direct relationship between the diatom production and the silica content of the water, since diatoms utilize silica to form their cell walls. Pearsall, in his study of English lakes, reported that diatoms were more abundant in the silted lakes than in the rocky lakes.

Algae give off oxygen in the growth process. This sometimes accumulates to the point of supersaturation in the water. The animal life, Protozoa as well as fish, use this oxygen and give off in turn carbon dioxide, which the plants use in their manufacture of food. When the balance of this mutually beneficial exchange of gases is upset, either the plants or the animals suffer. If the algae are destroyed in a pond supporting many fish, the subsequent lack of oxygen affects the fish directly as well as by indirectly limiting their food supply.

Olson has made interesting observations on the interrelationships of sunlight, algae, and fish. The amount of oxygen dissolved in the water varies with the temperature from 7.63 parts per million at 86° F. to 14.62 parts per million at 32° F., showing that the solubility of oxygen in water is greatest at low temperatures. In a lake or

stream at the end of a bright sunny day where the food-manufacturing activities of the algae have progressed at maximum rate, the oxygen eliminated by the plants loads the water beyond the point of saturation. At night when there is no sunlight, and photosynthesis or food manufacture ceases, the plants use a considerable amount of the oxygen thrown off during the day for respiration. Thus both the animal and plant life in the water are making demands on the available oxygen supply. When sewage or large quantities of decomposing organic matter present in the water make an increased demand on the oxygen supply, the nightly reduction in oxygen becomes serious. This is especially true when, owing to continued cloudy weather during the day, the oxygen supply is decreased and the water does not contain sufficient oxygen to last the night. When there is sewage pollution in a shallow body of water with little circulation, the oxygen is completely used up and the fish are exterminated. An extensive growth of blue-green or yellow-green algal bloom or scum is generally observed in ponds or lakes where high oxygen concentration occurs.

Thus it may be seen that when the proper balance between the amount of sunlight, concentration of plants, and number of fish in a pond is upset by cutting down the light so that the plants cannot perform their photosynthesis, they then enter into competition with the fish for oxygen, or the balance may be upset by an increase in plant organisms, or the fish may upset the balance by destroying the plants.

THE pH

The active acidity of a solution is usually indicated by the negative logarithm of the normal concentration denoted by the sign pH, the hydrogen ion exponent. The concentration of the hydrogen ions at neutral reaction is denoted by pH=7. As pH is a negative logarithm, the lower the designation of the pH, the higher the concentration of hydrogen ions and the more acid is the reaction. Organisms usually grow in a solution with a pH of 6 to 8.5.

TASTES AND ODORS IN THE WATER SUPPLY

The most familiar way in which algae make their presence known to us in the home is by their taste and odor so affecting the potability of the water that it is impossible to use it for drinking purposes. Consumers often prefer to drink water from private wells and springs, which may be of questionable sanitary quality, if they consider that their municipal water supply has an unpleasant odor or taste. The senses of taste and smell, although intimately associated, are distinct. Salt, for example, has a very definite taste but

no odor, while vanilla has a strong odor but no taste. The tastes of some substances are really odors due to gases perceived by the olfactory nerves through the nose or the posterior nares as the substance is placed on the tongue. The majority of the disagreeable tastes observed in water supplies are caused by organic matter in suspension, which produces both odors and tastes.

Water obtained from ground sources when used immediately is generally odorless. If it is kept in storage under certain conditions, or allowed to stagnate in parts of the distribution system, there is a resulting unpleasant odor. There are deep well waters that have an odor of sulfur and wells that may be polluted from surface drainage, which smell and taste moldy. The surface waters most frequently develop objectionable odors due to the presence of organic matter caused by decayed or living organisms (usually plankton), or to the chemicals used for disinfection of the water supply.

Complaints are made to the waterworks engineers by a few persons who are unusually sensitive to odors when microscopic organisms are present in 500 to 1,000 units (a standard unit is an area of 20 by 20 microns on a slide, or 400 square microns). When the organisms are present in 1,000 to 2,000 units, complaints become more numerous, and when above 2,000 units, complaints are general. Usually algicides are used when the concentration of algae reaches 1,000 units.

The chief odors noticed are aromatic (like geranium), caused by diatoms and a few Protoza; grassy, caused by blue-green algae principally, and by a few green algae; and fishy, caused by diatoms, green algae, and, chiefly, Protozoa. Among the diatoms, the most common offenders are *Asterionella* (pl. 3, fig. 5) and *Tabellaria*. They first make known their presence by an earthy odor which is generally characteristic of diatoms. As they increase in number, they produce an odor very similar to that of the geranium, then as they continue to multiply in great numbers, their odor is distinctly fishy. Most numerous offenders among the blue-green algae are *Anabaena* (pl. 4, fig. 2), *Aphanizomenon*, *Coelosphaerium*, *Clathrocystis*, and *Microcystis*. Their odor of fresh-cut grass changes to that of pungent nasturtium as they increase, until finally when they start decaying in large numbers, they smell like a vile pigpen. *Uroglena* and *Synura* are the worst offenders among the Protoza. *Uroglena* gives the water an oily, fishy taste and odor. In larger amounts, the flavor becomes more disagreeable, resembling cod-liver oil. A very small amount of *Synura* causes difficulty, as it gives a cucumber, muskmelon, or fishy taste that leaves a bitter after-taste at the back of the tongue. When the Protozoa are alive, the bitter taste is delayed a few moments, but when they are dead and decaying, the bitter

taste is observed immediately. The distasteful oil of *Synura* persists in a water supply for some time, so if *Synura* makes its presence known in the water supply in any small amounts, it should be immediately checked.

OTHER ALGAL NUISANCES

Masses of organisms in the water supply cause turbidity, and even a small amount of them may result in the formation of stain and scum on white porcelain basins and bathtubs. The tiny, slender plant, *Aphanizomenon*, which floats in the water even when dead, is able to accumulate in hot-water systems to such an extent as to appear in the surface water of a full bathtub.

In industry, the presence of algae in the water may cause trouble. They have been known to interfere with proper cleaning of clothes in laundries. Algae have prevented the formation of correct colors by dye manufacturers and have hindered the proper dyeing of goods. Bad results in the process of developing in photography have also been traced to the presence of algae in the water.

Because of the warm temperature of the water and the optimum lighting conditions, swimming pools are favorite places for algae to grow. The organisms become seeded on and between the tiles, which should be scrubbed with an algicide when the pool is emptied and cleaned.

Swimmer's itch, in one instance, was found to have been caused by *Cercaria elvae*, a parasite belonging to the group *Schistosoma*. It was found that snails carried these parasites, but the use of an algicide, such as copper sulfate, in doses of 0.5 to 2.0 parts per million destroyed the snails within 48 hours.

RED WATER

Often when complaints about the water are made to the water engineer, the cause of the difficulty is found to lie in a defective pipe line that delivers the water to the consumer. Due to the electrolytic action, iron from the pipe may go into solution. Some of the oxygen in the water then helps to change the soluble ferrous hydroxide to insoluble ferric hydroxide which precipitates in the pipe. If the water is very soft, the high content of the carbon dioxide increases the rate of corrosion. If the water is not treated, a deposit of organic matter may be found in the pipe line. The relatively high temperature increases this deposit during the summer, thus causing a further decrease in the amount of dissolved oxygen and an increase in the amount of carbon dioxide. The increased carbon dioxide further accelerates corrosion and the acid environment favors the growth of iron bacteria. The corroding action of the acid water produces a

red-colored water. Scraping and cleaning the pipes in order to regulate the operation of the reservoir so that only water containing low amounts of carbon dioxide enters the system somewhat reduces the difficulty. In the late summer months, the addition of lime to the water also prevents trouble.

SOURCES OF WATER SUPPLIES

The main reliance for the water supply is on rivers of various kinds, large and small, rapid and sluggish, pure and polluted. They also vary in the number and kinds of organisms to be found in them. The free-floating plankton population drifts with the current, feeding and reproducing as best it can. There is no stability or permanence for it even when the river is low and flowing fairly slowly but steadily, and floods are disastrous to the plankton. The river is fed from ponds and streams with quiet backwaters, and from all of these, plants of different kinds are passing into the main stream and replenishing the supply. Most rivers receive land washings, street drainage, and sewage drainage that carries the intestinal bacteria usually found in human and animal excrement. All of these intestinal bacteria soon lose their vitality in the water and sink to the bottom, thus decreasing in number between towns. The construction of large quiescent basins in which sedimentation can occur assists in the natural recovery from pollution, or the so-called self-purification of rivers. The water of such rivers is, however, unfit for domestic use until it has been chemically treated.

The towns in hilly districts are able to obtain their water from natural or artificial lakes. Usually, the land immediately surrounding and emptying into lakes and reservoirs is cleared of dwellings. Access to the lakes and reservoirs is restricted so that the water may be kept uncontaminated. In the temperate zone all lakes of considerable depth overturn twice each year, usually in the spring and in the fall. This phenomenon is caused in the autumn by the chilling of the surface waters, which makes them heavier than the lower waters. In the spring the slight warming of the surface waters, usually from 35° F. to 39° F., the temperature of the greatest density of water, causes a similar overturn. Normal stratification of the organisms in the lake is restored in 3 or 4 weeks' time in each case. This vertical movement causes a temporary commingling of the plant and animal organisms at the surface with those at the bottom.

STORAGE OF WATER

The advantage of storing water was demonstrated by Percy Frankland, who pointed out that the leap over Niagara Falls left the bacteria unharmed, whereas they disappeared very quickly in the quiet

waters of Lake Ontario. One of the first steps in the purification of water is its preliminary storage in reservoirs for at least a month before filtration. This gives suspended particles of all kinds time to settle. In addition, the water mixes so that possible variations in the supply are equalized. The numbers of intestinal bacteria decrease markedly.

The plankton passing from running water into still water tends to increase, and differences in the proportion of the different kinds result. Free-floating diatoms and algae might increase in the reservoir until it would teem with them but for the animals, especially the Crustacea, which abound in reservoirs and feed upon the plant life. On the sides of a reservoir may be found snails and creeping Crustacea, sessile diatoms, and larger attached plants. Fixed animals such as sponges flourish where there is solid support, and worms and duck mussels, as well as diatoms and bacteria, thrive in the accumulation of mud and detritus on the bottom.

All these living things eventually die and decay, to the advantage of the bacteria, but their increase is useful to the water supply. The plants help to aerate the water. Animals use up the oxygen for their respiration. They aid only in the measure that they prevent the algal growth from becoming too excessive. The kind of plankton in the reservoir also serves as an indicator to the engineer of the contamination of the source of the supply, as we have already seen in the case of the presence of *Bacillus coli.*

The plants and animals are not evenly distributed in the reservoirs but collect at particular levels. Algae usually abound where the light is most favorable; animals are in the places where there is plenty of food or where the chemical conditions (aeration) are most suitable. This is a useful fact to know, for by constructing the reservoir with outlet valves at different depths it is possible to draw water from the level that, as shown by the examination of the samples, is most suitable for filtration. Bottom water where the sedimented matter accumulates is not desirable, but generally the water should be drawn at a depth of 30 feet in a 40-foot reservoir. This takes the water at a level below that in which the algae are found. Since the levels poor in algae abound in their unused food material, their withdrawal aids in preventing abundant growth of algae.

These algal foodstuffs, chiefly phosphates and silicates, important as they are to the algae, do not affect the flavor of the water, since the quantities needed are negligible from the human standpoint. A water fairly rich in phosphates from the point of view of the algae may contain only 0.02 parts per 100,000. Such small quantities of phosphates are essential to human nutrition also. The silicates are harmless.

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THE WATER SUPPLY AND FILTRATION PLANT AT DALECARLIA

A typical modern city water supply system is that of the Dalecarlia Water Plant at Washington, D. C. The water supply of Washington, D. C., comes from the Potomac River, whose watershed extends back to the Shenandoah River, receiving streams from West Virginia and Pennsylvania as well as from Maryland and Virginia. The intake is at a low dam at the head of Great Falls, 16 miles above the center of the city. The average discharge at this point is 7,690 million gallons per day. At the time of the record low flow during the drought of the summer of 1930, the discharge dropped to 525 million gallons per day. Since the present daily maximum water consumption during the summer months is from 100 to 105 million gallons per day, or only one-fifth of the record low flow, it is evident that this river supply will suffice many generations.

The water flows by gravity through two conduits from an elevation of 151.6 feet above sea level at Great Falls for a distance of 9 miles to the inlet of the Dalecarlia Reservoir, which is at an elevation of 143.0 feet. This reservoir, which has a capacity of 210 million gallons, holds the water for 1 day before it goes into the filtration plant. This retention period with its change in velocity allows a heavy reduction in the turbidity of the water at periods of high mud content when the weight of suspended matter is often 3,000 parts per million. Not all the mud, however, is settled out, nor does much improvement result at times of low turbidity in the water when the weight of the suspended matter is 30 parts per million or less.

About 80 to 100 million gallons flow from the reservoir, part being drawn into the Dalecarlia filtration plant, part going to the MacMillan Park filters. An additional 120 million gallons is diverted daily to the hydroelectric plant.

As the water is drawn from the large Dalecarlia Reservoir for a distance of several hundred feet through a 6-foot conduit and Venturi meter to the rapid sand-filtration plant at Dalecarlia, a stream of aluminum sulfate is added. This coagulating agent mixes with the water as it passes through the conduit to the mixing basins, which are covered rectangular concrete basins about 10 feet deep, so built that the water passes backward and forward around a series of wooden baffles, causing the intermingling of all the water with the chemical. The amount of the aluminum sulfate or alum added varies, according to the amount of mud and the composition of the water as shown by the laboratory tests, from 145 to 450 pounds per million gallons. The time of the flow of the water through the mixing basins varies from 10 to 20 minutes, the time being governed by

the rate of filtration. Leaving these basins, the water flows into two large settling basins (pl. 1) built in pairs so that cleaning may be carried on without interruption of service. The water mixed with the alum enters these large basins, each of about 4 million gallons capacity. It requires about 3 hours to pass through, thus causing a low velocity which gives an opportunity for the settling of the aluminum floc formed when alum is added in properly regulated amounts to river water. In the formation of the floc, which is a chemical decomposition of the alum, all of the aluminum element is removed from the system and does not harm the water either from the point of view of potability or of hardness. When the water comes into these two basins, it is muddy, but when it goes out, it is clear, as it contains only a fine suspension of the floc.

With about 10 percent of the floc in suspension, this partly clarified water flows by gravity into 20 slow sand-filter units (pl. 2). The remaining floc forms a filtering mat on the sand surfaces, which strains out all suspended matter and entraps most of the bacteria.

Chlorine plus ammonia (chloramine) are also added to the water as it leaves the settling basins and goes into the filters. After the water has passed through the filters and sand beds, more chlorine is added. The amount of chlorine necessary to kill the small numbers of harmful intestinal bacteria present in this water is small.

Readjustment of the acidity is the final step at this plant. The water when it enters the plant usually has a low pH (hydrogen ion concentration or acidity) value. However, when alum is added to the water, hydrolysis occurs, for the aluminum sulfate is broken up into aluminum hydroxide and sulfuric acid. The former is the floc, which, settling, carries down the mud and the bacteria in the water. The sulfuric acid combines immediately with the lime or calcium carbonate normally present in river waters passing through limestone country and forms lime or calcium carbonate and frees carbon dioxide, which partially remains in solution and makes the water slightly acid. To remove this carbon dioxide, sufficient lime water is added to remove the gas but not enough to cause boiler-scale trouble.

The average turbidity of the water when it enters the plant is 140 parts per million; average hardness, 72; and average bacterial count, 2,500 per cc. The pH or acidity value is 7.6. After filtration, the turbidity is 0; hardness, 72; and the number of the bacteria is reduced to an average of 2 per cc. The pH of the filtered water is 8.0.

Lauter, from observations made at Dalecarlia, believes the covered reservoir is preferable to the open reservoir, since the covered type has a much smaller plankton count than the open type.

A TYPICAL INVASION OF DIATOMS

The troubles of a water engineer usually occur suddenly and without warning. An example of this occurred at the MacMillan Reservoir in Washington, D. C., in July 1938. During the early part of July there was no unusual evidence of organisms in the water. On July 26, however, there appeared, together with an upset oxygen and carbon dioxide balance in the water, large quantities of the diatom *Synedra pulchella* (pl. 3, fig. 1), which consists of several cells each 40 microns in length fastened together like a comb. Copper sulfate in large amounts was used to kill these diatoms. It was distributed from a skiff with an outboard motor which circled the reservoir and cross-hatched the dead pockets. The response of the organisms to the copper sulfate is shown by the following:

Date	*Single cells per cc.*	*Pounds of copper sulfate added*
July 26	1,692	
July 27	338	500
July 28	352	500
July 29	100	200
July 30	58	
July 31	0.9	
Aug. 1	0.0	
Total		1,200

A study of the bacterial records for the previous month showed that there had been a decided decrease in the bacterial efficiency and that the dissolved oxygen of the filtered water was as low as 50 percent and on some filters even 40 percent, whereas the normal summer-dissolved oxygen is usually never lower than 70 percent. The increased amount of carbon dioxide in the water undoubtedly caused increased diatom production which was already favored by the large silica content of the streams.

In 1934, when a large outbreak of *Synedra delicatissima* (pl. 3, fig. 2) occurred at Dalecarlia, one part per million of copper sulfate was added to the water for 3 days. The diatoms blocked the filters so completely that it was necessary to wash them every 15 minutes. Although the copper sulfate killed the microorganisms, they were not deposited in the settling basins, since they were about the same density as water.

As a rule, a dosage of 0.2 to 0.5 part of copper sulfate per million is sufficient to kill the plankton at Dalecarlia. Microorganic analysis is part of the regular routine. Samples of the water are collected from the river daily and run through the Sedgwick-Rafter filters for examination. Usually, the treatment is necessary only when turbidity is between 15 and 50 parts per million. When heavy waves of mud

come through, the algae entirely disappear and treatment can be omitted until the muddy waters subside.

JELLYFISH IN THE WATER SUPPLY

Occasionally, rare forms of plankton appear without apparent cause or warning in the filter beds only to disappear as quickly. In July 1927, when one of the filter beds was opened at Dalecarlia, thousands of the tiny jellyfish, *Craspedacusta sowerbii* (Lankester), came crowding to the light from all directions. After 2 weeks all had disappeared. No jellyfish were found in any of the reservoirs. The filter beds were in total darkness and there is very little circulation of air in them. At that time, their temperature varied from 71° to 75° F. During the time that the jellyfish were found in the filtration plant, the water 8 miles above this point was not being treated with alum and their sudden disappearance coincided with the resumption of the alum treatment. Scrapings of the filter beds revealed no trace of the hydroid generation, and their sudden visitation remains a mystery to this day.

CONTROL OF ALGAE

When there is difficulty with your water supply and you make a complaint to your city water department, each complaint is recorded and investigated. Four types of examinations are included in this investigation. The physical examination concerns the temperature, turbidity, color, and odor of both the hot and cold water. The microscopical examination relates to the quantity of microscopic organisms per cc., as well as to the amount of inorganic and amorphous matter. The bacteriological examination has to do with the number of bacteria per cc. and the presence of *Bacillus coli* and other bacteria associated with pollution. Finally, the chemical examination may include tests to show the total residue on evaporation, loss on ignition, fixed solids, alkalinity, hardness, incrustants, chlorine, iron, nitrogen as free ammonia, nitrogen as nitrites, total organic nitrogen, oxygen consumption, dissolved oxygen, and free carbonic acid, depending on the nature of the complaint.

Excessive growth of algae in reservoirs is usually controlled by the application of coagulants or algicides to the water. A coagulant acts indirectly by causing a chemical change in the water by which a flocculent or floc, a gelatinous material, is formed. This acts as a net entangling the algae, and then the whole mass sinks by its own weight to the bottom. Coagulants are generally those compounds that at contact with water form hydroxides of iron or aluminum in colloidal form. The compound used and the resultant reaction varies according to the chemical qualities of the water.

An algicide acts directly by killing the algae. Chloramine (ammonia and chlorine) and copper sulfate, used separately or together, and potassium permanganate are the algicides usually used. Very minute quantities of them are effective, and remaining traces of them are usually removed in the course of the subsequent sand-filtration. A few bacteria may remain after slow sand-filtration. Small quantities of chloramine are generally used to destroy these survivors. The chloramine treatment is preferable to chlorination (the use of chlorine alone) because the chloramine has greater power of destroying bacteria and does not leave the bad taste of chlorine in the water.

The following table, published by Hale and based on his experience and on data published by Moore and Kellerman, Whipple, and others, indicates the amount of copper sulfate and chlorine necessary to destroy some of the most frequently occurring plankton forms.

CHEMICALS REQUIRED FOR TREATMENT OF DIFFERENT GENERA OF PLANKTON

Organism	Odor	Copper sulfate		Chlorine
		Parts per million	*Pounds per million gallons*	*Parts per million*
Diatomaceae:				
Asterionella	Aromatic, geranium, fishy.	0. 12– 0. 20	1. 0– 1. 7	0. 5–1. 0
Cyclotella	Faintly aromatic			1. 0
Fragilaria		. 25	2. 1	
Melosira		. 20	1. 7	2. 0
Navicula		. 07	. 6	
Nitzschia		. 50	4. 2	
Synedra	Earthy	. 36– . 50	3. 0– 4. 2	1. 0
Stephanodiscus		. 33	2. 8	
Tabellaria	Aromatic, geranium, fishy.	. 12– . 50	1. 0– 4. 2	. 5–1. 0
Chlorophyceae:				
Cladophora		. 50	4. 2	
Closterium		. 17	1. 4	
Coelastrum		. 05– . 33	. 4– 2. 8	1. 0
Conferva		. 25	2. 1	
Desmidium		2. 00	16. 6	
Dictyosphaerium	Grassy, nasturtium, fishy.			. 5–1. 0
Draparnaldia		. 33	2. 8	
Eudorina	Faintly fishy	2. 00–10. 00	16. 6–83. 0	
Enteromorpha		. 50	4. 2	
Hydrodictyon	Very offensive	. 10	. 08	
Microspora		. 40	3. 3	
Palmella		2. 00	16. 6	
Pandorina	Faintly fishy	2. 00–10. 00	16. 6–83. 0	
Protococcus				1. 0
Raphidium		1. 00	8. 3	
Scenedesmus		1. 00	8. 3	
Spirogyra		. 12	1. 0	. 7–1. 5
Staurastrum	Grassy	1. 50	12. 5	
Tetrastrum				1. 0
Ulothrix		. 20	1. 7	
Volvox	Fishy	. 25	2. 1	. 3–1. 0
Zygnema		. 50	4. 2	

CHEMICALS REQUIRED FOR TREATMENT OF DIFFERENT GENERA OF PLANKTON—Continued

Organism	Odor	Copper sulfate		Chlorine
		Parts per million	*Pounds per million gallons*	*Parts per million*
Cyanophyceae:				
Anabaena	Moldy, grassy, vile	0. 12– 0. 48	1. 0– 4. 0	0. 5– 1. 0
Aphanizomenon	Moldy, grassy, vile	. 12– . 50	1. 0– 4. 2	. 5– 1. 0
Clathrocystis	Sweet grassy, vile	. 12– . 25	1. 0– 2. 1	. 5– 1. 0
Coelosphaerium	Sweet grassy	. 20– . 33	1. 7– 2. 8	. 5– 1. 0
Cylindrospermum	Grassy	. 12	1. 0	
Gloeocapsa (red)		. 24	2. 0	
Microcystis		. 20	1. 7	
Oscillaria		. 20– . 50	1. 7– 4. 2	1. 1
Protozoa:				
Ceratium	Fishy, vile, rusty brown color.	. 24– . 33	2. 0– 2. 8	. 3– 1. 0
Chlamydomonas		. 36– 1. 0	3. 0– 8. 3	
Cryptomonas	Candied violets	. 50	4. 2	
Dinobryon	Aromatic, violets, fishy.	. 18	1. 5	. 3– 1. 0
Endamoeba histolytica (cysts).				25. 0–100. 0
Euglena		. 50	4. 2	1. 0
Glenodinium	Fishy	. 50	4. 2	
Mallomonas	Aromatic, violets, fishy.	. 50	4. 2	
Peridinium	Fishy, like clam shells.	. 50– 2. 0	4. 2–16. 6	
Synura	Cucumber, muskmelon, fishy, bitter taste.	. 12– . 25	1. 0– 2. 1	0. 3– 1. 0
Uroglena	Fishy, oily, cod-liver oil taste.	. 05– . 20	0. 4– 1. 6	0. 3– 1. 0
Rotifer:				
Stentor		. 24	2. 0	
Crustacea:				
Cyclops				1. 0– 3. 0
Daphnia		2. 00	16. 6	1. 0– 3. 0
Schizomycetes:				
Beggiatoa	Very offensive decayed.	5. 00	41. 5	
Cladothrix		. 20	1. 7	
Crenothrix	Very offensive decayed, medicinal with chlorine.	. 33– . 5	2. 8– 4. 2	. 5
Sphaerotilis natans	Very offensive decayed.	. 40	3. 3	
Spirophyllum				. 25
Thiothrix				. 5– 1. 0
Fungus:				
Achlya				. 6
Leptomitus		. 40	3. 3	
Saprolegnia		. 18	1. 5	
Miscellaneous:				
Chara		. 10– . 50	. 8– 4. 2	
Nitella flexilis	Objectionable	. 10– . 18	. 8– 1. 5	
Potamogeton		. 30– . 80	2. 5– 6. 7	
Nais				1. 0
Blood worm, chironomus.				15. 0– 50. 0
Blood worm, gnats				3. 0

Sometimes fish are killed by the chemicals used in sterilization of the water. Moore and Kellerman prepared the following table, which shows the susceptibility of fish to the chemical, copper sulfate.

LIMITING SAFE DOSAGE OF COPPER SULFATE

Fish	Parts per million	Pounds per million gallons
Trout	0. 14	1. 2
Carp	0. 33	2. 8
Suckers	0. 33	2. 8
Catfish	0. 40	3. 5
Pickerel	0. 40	3. 5
Goldfish	0. 50	4. 2
Perch	0. 67	5. 5
Sunfish	1. 35	11. 1
Black bass	2. 00	16. 6

More and more in recent years, scientists and waterworks engineers have become concerned with the interrelationship of microscopic plants and animals and their relationship to their environment, which in turn is very intimately related to our own daily life. The quest for knowledge regarding these tiny organisms in our water supply continues daily, and in the meantime our provision of pure water is made more secure.

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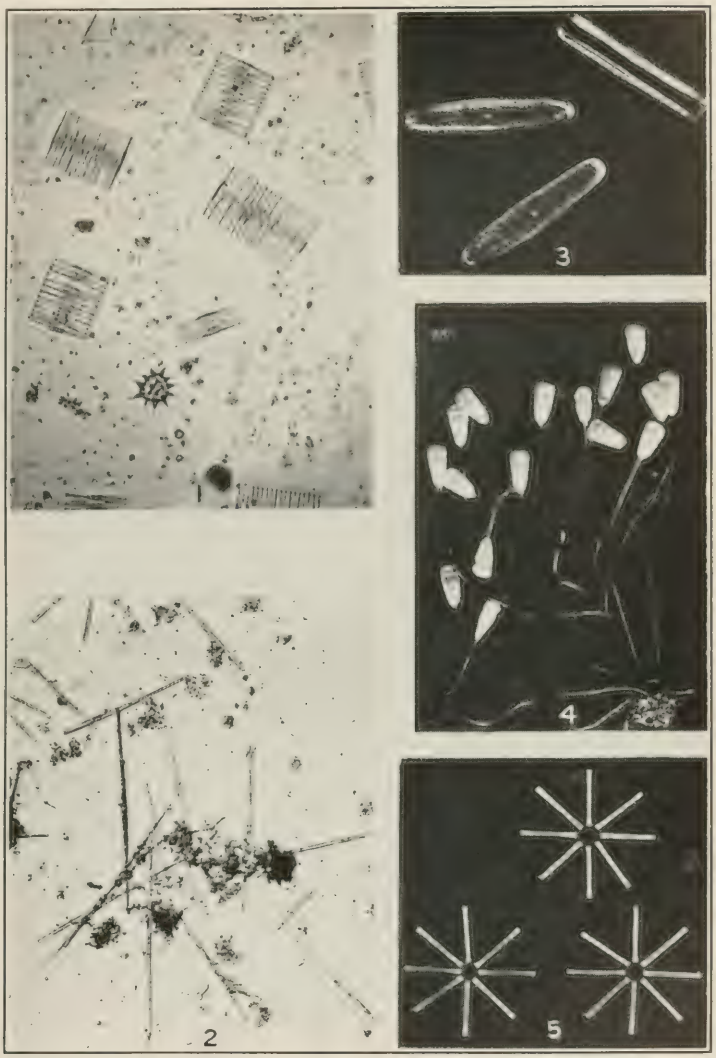
Courtesy of Carl J. Lauter.

THE SETTLING BASINS AT THE DALECARLIA FILTRATION PLANT, WASHINGTON, D. C.



Courtesy of Carl J. Lauter.

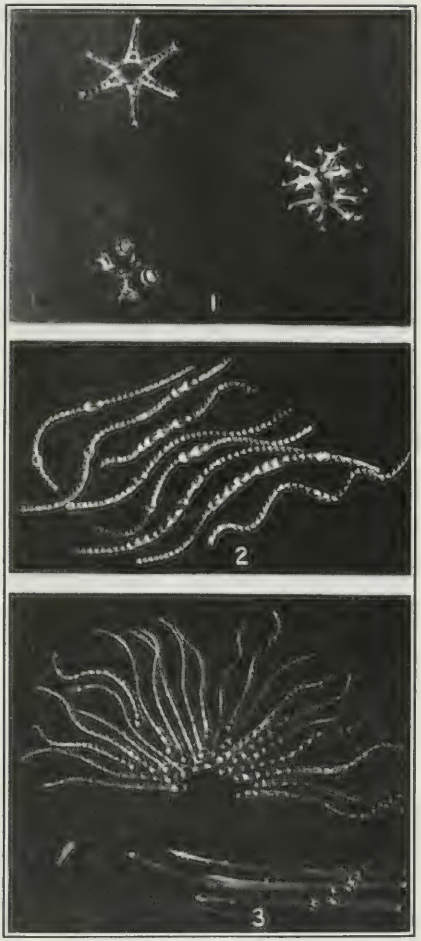
THE FILTER UNITS AT THE DALECARLIA FILTRATION PLANT, WASHINGTON, D. C.



Courtesy of U. S. Public Health Service.

DIATOMS COMMONLY FOUND IN WATER SUPPLIES.

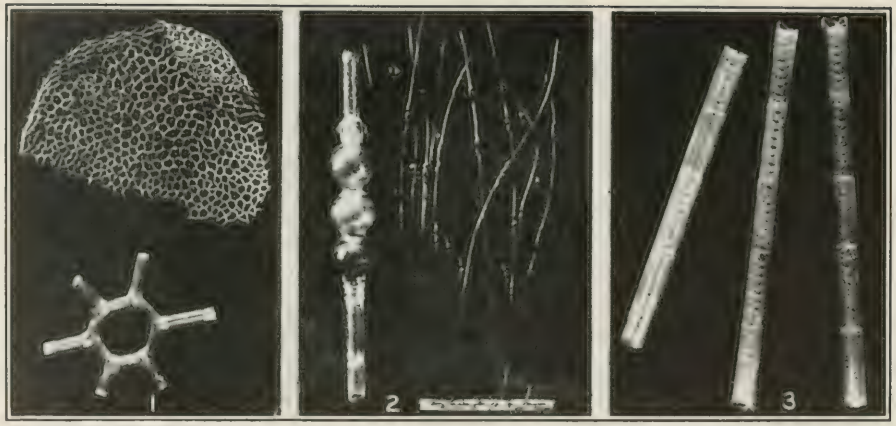
1, *Synedra pulchella* with a solitary *Pediastrum*, an alga; 2, *Synedra delicatissima* with alum floc. (Photomicrographs by Carl J. Lauter.) 3, *Navicula;* 4, *Gomphonema;* 5, *Asterionella.* Greatly magnified.



Courtesy of U. S. Public Health Service.

NUISANCES IN WATER SUPPLIES

1. *Staurastrum*, a desmid; 2, *Anabaena*, a blue-green agla; 3, *Rivularia*, a blue-green alga. Greatly magnified.



Courtesy of U. S. Public Health Service.

GREEN ALGAE.

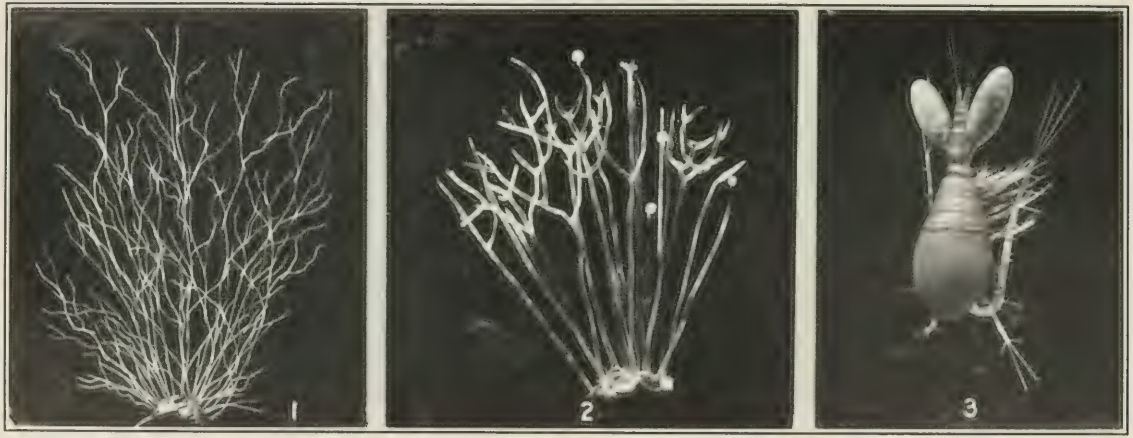
1, *Hydrodictyon;* 2, *Oedogonium;* 3, *Spirogyra.* Greatly magnified.



Courtesy of U. S. Public Health Service.

PLANKTON.

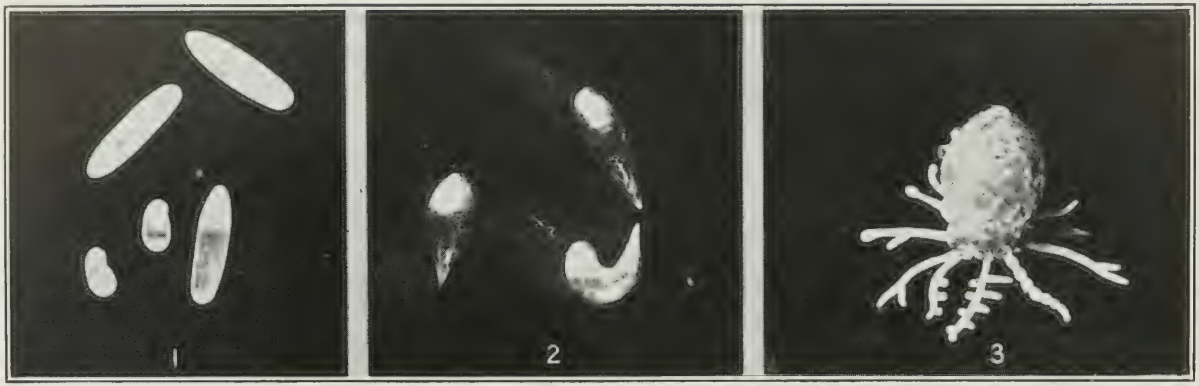
1, *Closterium*, a desmid of hard waters; 2, *Cladophora*, a common fresh-water green alga; 3, *Bodo*, a flagellate often found in strongly polluted waters. Greatly magnified.



Courtesy of U. S. Public Health Service.

PLANKTON.

1, *Sphaerotilus*, bacteria; 2, *Saprolegnia*, a fungus often causing a disease of fish; 3, *Cyclops*, a crustacean. Greatly magnified.



Courtesy of U. S. Public Health Service.

PROTOZOANS.

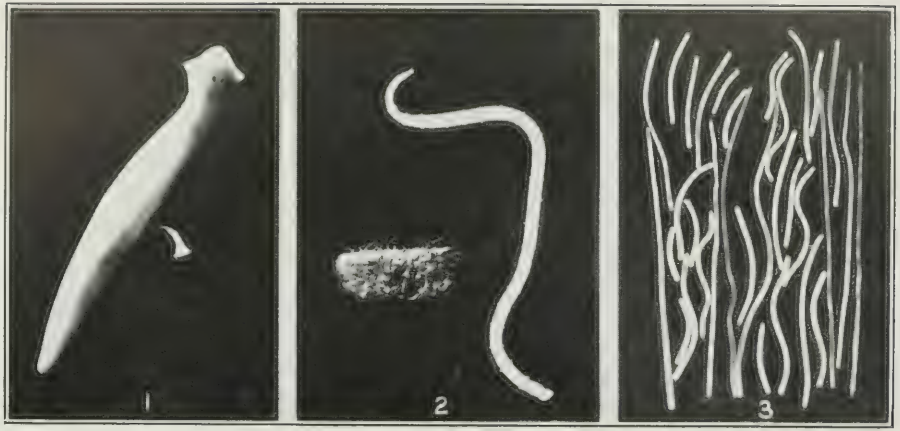
1, *Paramoecium* and *Colpodium;* 2, *Euglena;* 3, *Difflugia*. Greatly magnified.



Courtesy of U. S. Public Health Service.

PROTOZOANS.

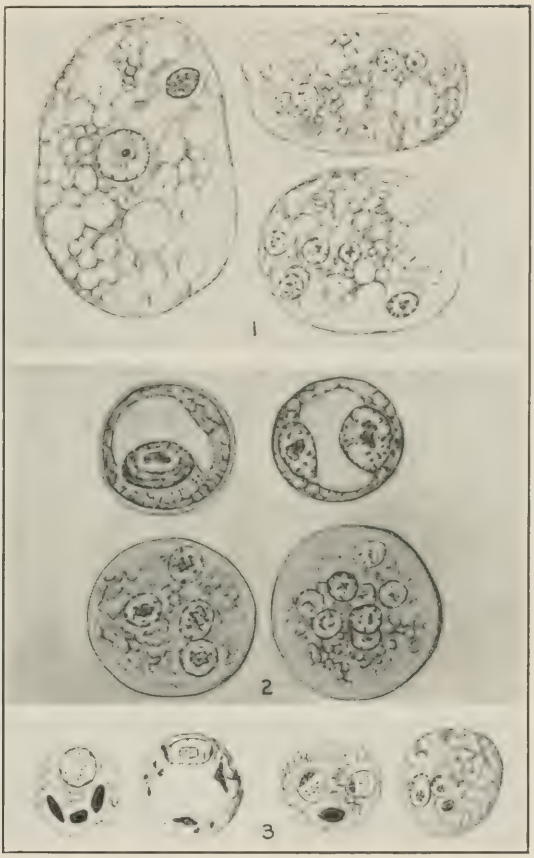
1, *Carchesium;* 2, *Vorticella;* 3, *Arcella.* Greatly magnified.



Courtesy of U. S. Public Health Service.

PLANKTON.

1, *Planarian*, a worm; 2, *Limnodrilus*, a worm; 3, *Beggiatoa*, sulfur bacteria commonly found in sewage-laden streams. Greatly magnified



Courtesy of U. S. Public Health Service.

PROTOZOANS.

1, Three stages of a nonpathogenic endamoeba of man; 2, four stages of spore formation of a nonpathogenic endamoeba of man; 3, stages of *Entamoeba dysenteriae*, the parasite of amoebic dysentery of man. Greatly magnified.

TRICHINOSIS IN SWINE AND ITS RELATIONSHIP TO PUBLIC HEALTH[1]

By Benjamin Schwartz,
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INTRODUCTION

Trichinosis is a disease of human beings, swine, and other animals, and is of interest, therefore, to physicians, veterinarians, and public health and livestock sanitary officials and workers. This disease concerns also farmers and other swine growers because it is contracted by hogs as a result of certain swine husbandry practices. The meat and meat-packing industries are also vitally affected by the presence of trichinae in hogs, the transmission of these parasites to human beings through the consumption of raw or inadequately cooked or processed pork resulting in lawsuits for the recovery of damages on account of illness or death. This paper discusses trichinosis from the biological standpoint and as a problem concerning public health, livestock sanitation, veterinary medicine, and the meat and meat-packing industries, and outlines methods of controlling this important human and animal disease.

THE DISCOVERY OF TRICHINAE AND THE DEMONSTRATION OF THEIR LIFE CYCLE

Trichinae were first discovered in swine by Joseph Leidy, an American physician and naturalist. Leidy communicated his discovery to the Philadelphia Academy of Natural Sciences in October 1846; the published report (1) [2] of this communication prepared by the Academy's secretary is as follows:

> Dr. Leidy stated that he had lately detected the existence of an Entozoön in the superficial part of the extensor muscles of the thigh of a hog. The Entozoön is a minute, coiled worm, contained in a cyst. The cysts are numerous, white, oval in shape, of a gritty nature, and between the 30th and 40th of an inch in length.

[1] Reprinted by permission from the Journal of the American Veterinary Medical Association, vol. 92, n. s., 45, No. 3, pp. 317–337, March 1938, with slight revision and amplification by the author (August 1939).

[2] Numbers in parentheses refer to list at end of article.

The Entozoön he supposes to be the *Trichina spiralis*, heretofore considered as peculiar to the human species. He could perceive no distinction between it and the specimens of *T. spiralis* which he had met with in several human subjects in the dissecting-rooms, where it has also been observed by others, since the attention of the scientific public has been directed to it by Mr. Hilton and Professor Owen.

In March 1866, 20 years after Leidy communicated his finding of trichinae in pork, that investigator (2) explained at a meeting of the same academy the circumstances under which he had made this important discovery. Briefly the circumstances were as follows: While eating a slice of pork, Leidy observed some minute specks in the meat which reminded him of similar spots that he had seen in the muscles of a human cadaver only a few days previously. He saved part of the pork, and upon examining it microscopically he found it to be copiously infested with trichinae. The parasites were all dead, since the piece of pork in question had been thoroughly cooked. It is noteworthy that Leidy was quoted as observing that all meats were liable to be infested with parasites. He stated, however, that there was no danger in this to human beings, provided the meats were thoroughly cooked. Leidy stated that he had satisfied himself by experiment that parasites were destroyed when subjected to the temperature of boiling water.

As far as is known, Hilton (3), a prosector in Guy's Hospital, London, was the first to investigate the white, gritty specks found by him in a human cadaver; there is some evidence that similar specks were found by Tiedemann, in 1822, and by Peacock, in 1828. In 1832,[3] Hilton examined these pathological spots without recognizing, however, any parasites within them. In 1835, Paget, then a medical student in London, found whitish spots in a human cadaver which he dissected in St. Bartholomew's Hospital. With the aid of Brown and Bennett, Paget demonstrated that the white, gritty spots were capsules which contained spiral worms. These worms were described in the same year by Richard Owen (4), and named by him *Trichina spiralis*. In 1895, Railliet (5) renamed these parasites *Trichinella spiralis* because the generic name *Trichina*, proposed by Owen, was preoccupied and, under the rules of zoological nomenclature, was not available for the parasite under discussion.

From the time of the discovery of trichinae in human cadavers until 1860, these worms were regarded as zoological curiosities, although, according to Leuckart (6), Wood, in Bristol, discovered numerous trichinae in the body of a young man who died in 1835, after a 3-weeks illness characterized by rheumatic symptoms, accompanied by cardiac and pulmonary inflammation. According to

[3] His observations were published in 1833.

Leuckart, Wood expressed the opinion that the presence of the trichinae might have been related to the rheumatic and inflammatory condition of the patient. It was not until 1860, however, that trichinae were definitely recognized as pathogenic. This came about as follows:

On January 27, 1860, a 20-year-old girl died in the municipal hospital of Dresden, Germany, the suspected cause of death being typhoid fever. On microscopic examination of the girl's muscles, Zenker (7) found numerous trichina larvae in various stages of development, including larvae that had apparently invaded the muscles recently. However, Zenker failed to find the usual pathological picture of typhoid fever in the course of this necropsy. On investigating this matter further, Zenker determined that, 38 days before her death, the girl had eaten sausage and ham prepared from a hog that had been slaughtered on a farm where she had been a servant. Others who had partaken of this pork also became ill and Zenker was able to demonstrate numerous trichinae in the remaining portions of the meat that were still available. Later Zenker demonstrated trichinae in the girl's intestines that had been preserved in cold storage. With material obtained from the girl's muscles, Zenker, Virchow, and Leuckart worked out the essential facts in the life history of trichinae. Leuckart (8) experimentally infected a hog with trichinous meat and, several days later, he observed symptoms suggestive of an intestinal infection, and fever. The symptoms gradually increased in severity and became complicated by the appearance of muscular stiffness, the animal in question being hardly able to move 4 weeks following experimental infection. On postmortem examination, 5 weeks after the beginning of the experiment, Leuckart demonstrated unencysted trichinae in the muscles of the pig.

On the heels of these important discoveries concerning trichinae and their mode of transmission, serious epidemics of trichinosis came to light in Germany. In 1862 there occurred in the town of Hettstädt a massive epidemic of trichinosis with a mortality of 16 percent, due to the consumption of raw pork. Two years later, 337 individuals in a small town in Saxony, having a total population of 2,000, developed trichinosis and, of those that became so affected, 101 died. These two epidemics forcefully demonstrated the role of uncooked, trichina-infested pork in the transmission of a serious disease to human beings.

LIFE HISTORY OF TRICHINAE

Knowledge of the life cycle of *Trichinella spiralis* is the result of scientific investigations carried out by various parisitologists and

medical investigators, in addition to those already mentioned. Briefly the life cycle is as follows (fig. 1):

Infection in a human being, pig, or other susceptible animal, takes place as a result of the ingestion of meat containing live, infective larvae. The infective larvae, 1 mm. (about $\frac{1}{25}$ of an inch) long, are located in the muscle fibers where they are spirally rolled, and enclosed in connective tissue cysts. On reaching the stomach of a susceptible host that happens to ingest trichinous meat, the



FIGURE 1.—Life cycle of *Trichinella spiralis*. (After Schwartz.)

larvae become free as a result of proteolytic enzyme activity, and the liberated worms pass into the intestine with the chyme. Here they become localized, at first among the folds and villi in the upper part of the small intestine, and become sexually mature in the course of 2 or 3 days, meanwhile increasing somewhat in size. Following the mating of the worms, the females rapidly attain their growth, reaching a length of 3 to 4 mm. (about $\frac{1}{8}$ to $\frac{1}{6}$ of an inch), burrowing more or less deeply into the intestinal mucosa, and commonly reaching the lymph spaces of the villi. The full-grown males, which

attain a length of 1.5 mm. (about 1/16 of an inch), tend to pass out of the intestine shortly after their reproductive functions have been completed. However, adult worms of both sexes may persist in the intestine for several weeks.

The fertilized eggs develop within the uterus of the mother worm, and the larvae begin leaving the maternal uterus 4 to 5 days after the mating of the sexes, or 6 to 7 days after the ingestion of trichinous meat by a susceptible host. While the birth of young worms may continue for several weeks, most larvae are apparently discharged by the adult females during the first 2 weeks of their fertile period.

The new-born larvae, 0.1 mm. (about 1/250 of an inch) long, are deposited in the lymph spaces through the vaginal aperture of the female trichina, this aperture being located in the anterior part of the worm. The larvae are carried by the lymph to the thoracic duct, thence through the venous system into the heart, and finally into the arterial circulation. Those larvae which are carried to the striated muscles leave the capillaries and penetrate into the primary muscle bundles. The muscle fibers become most heavily invaded 9 to 10 days after infection, or 3 to 4 days after the birth of the young worms has begun. Within 10 to 14 days after their penetration into the muscles, the larvae have attained their maximum length, which is 10 times their original length; each larva rolls itself into a spiral and becomes enclosed in a capsule.

While the origin of the capsule is still a somewhat debatable point, it is certain that the presence of the parasites in the muscle fibers stimulates the formation of connective tissue around each worm; sometimes, however, two, and more rarely more than two, worms are enclosed in a single capsule. Capsule formation begins about 1 month after infection, and a thin-walled capsule is readily recognizable about 6 weeks after infection. Sooner or later, but not earlier than 6 months after infection, as a rule, the capsules begin to calcify, calcium being deposited at first at the poles, the entire process of calcification requiring about 1½ years. This accounts for the failure to find the white, oval cysts in infested pork, since most hogs that come to slaughter in this country are approximately 6 to 10 months old. In the experience of the author of this paper, only one specimen, among the numerous samples of pork examined for trichinae in the laboratory of the Zoological Division and elsewhere, contained calcified cysts, visible to the naked eye as small, oval, chalky spots, such as were observed and described by Leidy in 1846 (1). The larvae may remain alive in the calcified cysts for a number of years. Sooner or later, however, the larvae die and become absorbed, or undergo calcification and break down into crumbled masses.

Wandering trichinae have been found also in the mesenteric lymph-nodes, peritoneal cavity, pericardial cavity, pleural cavity, myocardium, lungs, the central nervous system and other locations. In these locations only the young noninfective larvae have been encountered; the infective larvae are known to occur only in muscle fibers that are surrounded by sarcolemma. While trichina larvae are known to penetrate the tissue of the heart, they are unable to develop there and degenerate rapidly. As a result of their penetration into the heart tissue, the larvae produce profound inflammatory and degenerative changes, and these parasites may be one of the factors in cardiac diseases in man and animals.

It is evident from this account of the life cycle that the entire development of *Trichinella spiralis* takes place in a single host animal which harbors at first the developing and sexually mature worms in its intestine, and later harbors the new generation of worms in the lymph, the blood, and finally in the voluntary muscles.

FACTS LEADING TO THE DETERMINATION OF THE PREVALENCE OF TRICHINAE IN HOGS IN THE UNITED STATES

It could hardly be expected that the discovery of trichinae in hogs would be without its effect on the American meat industry, particularly following the alarming outbreaks of trichinosis in Germany. When Europe became trichina-conscious and alarmed, American meat exporters had already carried on for a number of years a brisk trade with various countries on that continent. According to Mohler (9) the export trade in bacon alone from the United States to Europe had become well established in 1879. As a result of the trichinaphobia which held the peoples of certain European countries in its grip, restrictive measures against American pork began to be promulgated, Italy, Germany, Austria, and France following each other in rapid succession. The prohibition against American pork was operative in the countries mentioned by 1881. These restrictions, together with the "Slaughter Order" of Great Britain in 1892, which required that cattle imported from the United States be slaughtered at a port of entry because of the fear of contagious pleuropneumonia, are considered by Mohler (9) "as the potent and exciting factors in securing legislation for the scientific inspection of meats for foreign and domestic use, and, incidentally, in advancing the cause of veterinary science in the United States." Thus, an observation by Leidy and the subsequent scientific discoveries which followed in its wake were responsible, at least in part, for giving the American people the protection that is afforded by the Federal Meat Inspection Service.

On August 30, 1890, the Congress of the United States passed an act providing for the inspection of salted pork and bacon, and on March 3, 1891, the Congress passed a more effective meat inspection

act that provided, among other things, for a microscopic inspection of meat from all hogs for export in order that certificates could be issued setting forth their freedom from trichinae.

PREVALENCE OF TRICHINAE IN HOGS IN THE UNITED STATES

As a result of systematic microscopic examinations of samples of muscle tissue from millions of hogs, there accumulated in the records of the Bureau of Animal Industry a vast array of data showing the prevalence of trichinae in swine in this country. These data, which were made public from time to time, showed that out of the total of over 8,000,000 hogs, samples of which were examined microscopically from 1898 to 1906, 1.41 percent contained live trichinae; in addition, 1.16 percent contained bodies resembling trichinae or disintegrating trichinae. The total percentage of infection with live and dead or disintegrating trichinae was more or less uniform from year to year during the 9-year period mentioned.

Since it is well known that microscopic inspection is inherently imperfect, and that light and occasionally moderate infections are likely to be overlooked, it is safe to conclude that during the period covered by the data mentioned, approximately 1 out of 75 hogs contained trichinae probably in sufficient numbers to cause clinical trichinosis in human beings following the consumption of such pork in a raw or insufficiently cooked state. Under the meat inspection act passed by Congress in 1906, there was no specific provision for microscopic inspection for trichinae of pork intended for export, and the inspection previously made was discontinued.

Following the abandonment, in 1906, of microscopic inspection for trichinae of pork intended for export, no up-to-date information was available up to 1933 regarding the prevalence of these parasites in swine. In 1933, there was inaugurated in the Bureau of Animal Industry, under the direction of the writer, a research project involving a thorough examination of samples of pork muscle tissue for trichinae by the laborious technique of digesting from each carcass about 200 to 250 grams of muscle tissue taken from the pillars of the diaphragm. While microscopic examination of pork for trichinae is a hit-and-miss method, the digestion method as described by Ransom (10), with certain modifications introduced by workers in the Zoological Division, is the most accurate technique known at present for determining the presence or absence of trichinae in pork and any other meat. The information obtained by the writer and his associates on the prevalence of trichinae in swine is applicable to research only. This method gives a far more accurate insight into the incidence of trichinae in hogs than was obtained by the routine microscopic inspection practiced by Bureau inspectors from 1892 to 1906.

Out of 6,622 samples of diaphragm muscle tissue obtained from 1933 to 1937 from as many grain-fed hogs originating in Alabama, Florida, Georgia, Illinois, Kentucky, Michigan, Minnesota, Missouri, New Jersey, New York, and Ohio, and slaughtered in officially inspected establishments, only 60 (0.91 percent) were found to be infested with trichinae. Of those found to be so infested, nearly one-third contained between only 1 and 5 larvae per 100 grams of diaphragm muscle tissue; slightly over one-sixth of the positives contained only between 6 and 25 larvae per 100 grams of diaphragm muscle tissue; of the remainder, constituting 52 percent of the positive samples, one or more trichinae were found per gram of diaphragm muscle tissue, and only about two-thirds of these contained in excess of more than one larva per gram of muscle tissue.

Out of 6,484 samples obtained from as many hogs that had been fed on uncooked garbage, 286 (4.41 percent) were found to be infested. Of the samples so infested more than two-fifths contained only from 1 to 5 larvae, and more than one-fifth contained only from 6 to 25 larvae per 100 grams of diaphragm muscle tissue; of the remaining samples which contained one or more larvae per gram of muscle tissue, only two-thirds contained more than one larva per gram of such tissue.[4] Out of 1,987 samples obtained from as many hogs known to have been fed cooked garbage, 11 (0.55 percent) were found to be infested. Of those so infested, nearly 45 percent contained only from 1 to 5 and about 18 percent contained only from 6 to 25 larvae per 100 grams of diaphragm muscle tissue. Of the remaining 29 percent, which contained 1 or more larvae per gram of diaphragm muscle tissue, only 0.9 percent contained more than 1 larva per gram of such tissue.

These data show an incidence of trichinae in garbage-fed hogs about five times as great as that in grain-fed hogs, and an incidence of these parasites in hogs fed uncooked garbage about eight times as great as that in hogs fed cooked garbage. The data show, therefore, that the feeding of uncooked garbage favors the spread of trichinae to swine and that the cooking of garbage is an effective method of sharply curtailing the incidence of trichinae in garbage-fed hogs.

[4] Since this paper was written a total number of 13,162 diaphragms from as many grain-fed hogs were digested with the following results: Only 126 (0.95 percent) were found to contain trichinae and nearly two-thirds of the positives contained only 1 to 5 larvae per 100 grams of tissue; less than 25 percent of the positives contained 1 or more trichinae per gram of tissue. Out of 10,500 diaphragms from as many garbage-fed hogs obtained from important garbage-feeding centers, 599 (5.7 percent) were found to be infected. Of the positives 228 (38 percent of the whole) contained only 1 to 5 larvae per 100 grams of tissue; slightly over 25 percent of these positives contained 1 or more trichinae per gram of tissue.

The available evidence shows that the majority of the positive grain-fed hogs had light infections with trichinae, this being correlated with the preponderance of low-grade human trichina infections brought to light by the examination of human diaphragms. Grain-fed hogs constitute the vast bulk of swine in the United States.

In general, the incidence of trichinae involved in the series of hogs in question is low. Data to be presented in another section of this paper show that hogs that developed infections with trichinae produced by the experimental feeding of trichinous meat did not show clinical symptoms when the resulting infection was characterized by less than 800 to 900 larvae per gram of diaphragm muscle tissue. In the entire series of over 15,000 hogs involved in the digestion tests to determine the presence of trichinae, only one contained as many as 805 larvae per gram of diaphragm muscle tissue. With the possible exception of this particular hog, not one of the other infested animals under consideration would have been diagnosed as suffering from trichinosis even if all of these hogs had been under the careful scrutiny of a competent veterinary clinician during the period of active infection. The trichina infections in the 357 positive hogs, with the possible exception of the one hog already mentioned, were evidently of the nonclinical type, as far as can be judged by the number of larvae present in the diaphragms of these individual host animals.

Data obtained by the writer and his associates in the Zoological Division showed that when the infection with trichinae in the pillars of the diaphragm of hogs was such that less than 1 larva was present per gram of muscle tissue, only 1 out of 11 positive samples, examined microscopically three times, actually showed trichinae. When the infection was characterized by as many as 3 larvae per gram of diaphragm muscle tissue, only approximately 50 percent of the known positives showed trichinae on miscroscopic examination. Out of a total of 319 diaphragm samples from as many trichina-infested hogs found to be positive by the digestion technique, only 67 (21 percent) were found to be positive by the press preparation method when three preparations, each containing between 100 and 150 milligrams of muscle tissue, were examined. Assuming these findings to have general application, the positive samples in the series under discussion would have been sharply reduced, had these samples been examined only microscopically.

TRICHINOSIS IN SWINE

Considering the fact that a positive diagnosis of trichinosis in human beings can be made with certainty only when the parasites are actually found in the patient, usually following a biopsy, it is not surprising that Hutyra and Marek (11) state that trichinosis has not been diagnosed in living swine. In a human being a tentative diagnosis of trichinosis is made on the basis of a chain of clinical symptoms, not a single one of which, or even several taken together, can be regarded as pathognomonic of this disease. However, when all the symptoms are considered together, a presumptive diagnosis is warranted, particu-

larly if the patient can recall having eaten, prior to the onset of symptoms, raw or insufficiently cooked pork, or an inadequately processed or cooked meat food product containing pork muscle tissue. In the final analysis, however, a definite diagnosis of trichinosis involves the finding in the patient of the parasites at some stage of their development.

The clinical manifestations of trichinosis in swine have been established only as a result of observations following experimental feeding of trichinous meat to these animals. The severity of the symptoms in swine, as in human beings, is related to the number of encysted larvae ingested. This accounts for the somewhat conflicting reports relative to the seriousness of trichinosis in swine, as recorded by different investigators. In general the work of the early investigators showed that swine manifest symptoms following the ingestion of relatively large numbers of trichinae, and that indefinite or no symptoms are shown by these host animals following the ingestion of relatively small numbers of these worms.

Thus, Leuckart (6) concluded that only about 50 percent of hogs that had been infected experimentally showed visible symptoms. According to Leuckart, the hogs that were seriously affected showed intestinal disturbances 3 to 4 days after eating trichinous meat. In the severest cases, Leuckart noted intestinal irritation, fever and pain, and on the eleventh day after infection, he observed a sharp increase in temperature with evidence of muscular inflammation, stiffness, difficulty in masticating and breathing, and severe emaciation. Leuckart found that about 50 percent of the hogs showing severe symptoms succumbed to trichinosis. In recovered cases, this investigator observed the subsidence of the symptoms beginning about 6 weeks after infection; recovery was complete, the recovered animals taking on good weight.

In the course of experimental investigations on trichinae in hogs carried out during the past few years by Lloyd A. Spindler, of the Zoological Division of the Bureau of Animal Industry, under the direction of the writer, observations were made on the reactions of these host animals to various doses of larvae administered. Although these observations were incidental to other objectives, they are of value in showing the varying degree of susceptibility of pigs to different-sized doses of trichinae. When the pigs in question were killed, an estimate was made of the number of larvae per gram of diaphragm muscle tissue by the digestion method proposed by Ransom (10). The results of these observations, together with other pertinent data, are given in table 1.

An examination of the data presented in table 1 shows that pigs 1 to 6 weighing from 100 to 150 pounds, showed no readily observable symptoms following the ingestion of trichinous meat containing vary-

TABLE 1.—*Results of experimental infection of pigs with trichinae*

Pig	Weight	Larvae administered		Symptoms shown by pigs	Larvae per gram of diaphragm muscle
		Total	Per kilogram		
	Kilogram				
1	45.45	1,200	26	None	10.
2	56.82	10,000	176	do	100.
3	61.36	20,000	326	do	100.
4	68.18	30,000	440	do	300.
5	54.55	25,000	458	do	280.
6	54.55	35,000	641	do	322.
7	90.91	75,000	825	do	900.
8	59.09	80,000	1,354	Pig "off feed" from 14th to 27th day after infection	Not determined.
9 [1]	45.45	80,000	1,760	Diarrhea and prostration beginning the third day after infection; animal died 7 days after infection.	Do.[2]
10	34.09	90,000	2,640	Pig "off feed" and inactive from 15th to 23d day after infection.	860.
11 [1]	52.27	100,000	1,913	"Off feed" 7 days after infection; prostrated 10 days after infection; died 10 days after infection.	Not determined.[2]
12 [1]	52.27	100,000	1,913	Symptoms as above; died 12 days after infection	Do.[2]
13 [1]	52.27	100,000	1,913	Symptoms as above; died 14 days after infection	Do.[2]
14 [1]	52.27	100,000	1,913	Symptoms as above; died 15 days after infection	Do.[2]
15 [1]	52.27	100,000	1,913	Symptoms as above; died 18 days after infection	Do.[2]
16 [1]	52.27	100,000	1,913	Symptoms as above; died 20 days after infection	Do.[2]
17 [1]	45.45	120,000	2,640	Prostrated 12 days after infection; died 24 days after infection.	1,820.
18 to 23	68.18 to 72.72	[3] 120,000	1,650 to 1,760	Animals obviously sick 10 to 12 days after infection, remaining so for 10 to 14 days; refused feed for several days; stiff and moving with difficulty.	1,800 to 2,700.
24	104.54	120,000	1,148	Diarrhea 4 days after infection; "off feed" and inactive from 4th to 20th days after infection.	1,200.
25	68.18	125,000	1,833	Slight; "off feed" for about 2 weeks, beginning 12 days after infection.	1,000.
26	40.91	174,000	4,253	"Off feed" about 1 week after infection; refused feed 10th to 12th day after infection; drank large quantities of water; muscular stiffness pronounced; pig hardly able to get up.	2,100.

[1] Succumbed to the infection; all other pigs in this series were killed to obtain a supply of trichinous meat.
[2] The larvae are killed by digestion before they attain the infection stage.
[3] Fed to each pig.

ing numbers of infective larvae, the number of larvae ingested by individual pigs of this group ranging from 1,200 to 35,000. Since a single female trichina may give birth to about 1,000 larvae, the individual pigs in question might have contained from about 500,000 up to about 17,000,000 larvae in their muscles. This estimate is based on the assumption that 50 percent of the larvae administered developed into females and that each of the latter developed to fertile maturity and produced a normal brood of young worms. It is doubtful, however, that such theoretical expectations are ever realized in the case of experimental and natural infections. It is fairly safe to conclude that pig 6 that received 35,000 infective larvae probably developed an infection characterized by the encystment of several million larvae in its muscles, without exhibiting, however, any noticeable clinical symptoms.

Although a 200-pound hog (No. 7) was apparently unaffected following the ingestion of 75,000 larvae, two pigs weighing 100 pounds (No. 9) and 130 pounds (No. 8), respectively, showed symptoms, those in the lighter pig being decidedly pronounced and terminating in death 7 days after infection. The remaining pigs of this series received doses of from 90,000 up to 174,000 larvae and all of them showed more or less severe symptoms. Each of six pigs (Nos. 11 to 16), weighing about 115 pounds and receiving a dose of 100,000 larvae, succumbed to the infection at various times between the tenth and twentieth days following the ingestion of larvae. It is interesting to note that the top of the mercury column in the thermometer used in taking the temperature of pig 16, about 1 hour before this animal died, was above the mark 110° F. Pig 26, weighing 90 pounds and receiving 174,000 larvae, showed severe symptoms but it did not succumb to the infection.

It is evident from these data that infections resulting from the administration of trichinae may be measured by the number of larvae per gram of diaphragm muscle tissue. Applying this yardstick to the data given in table 1, it is clear that in the series of experimental infections under consideration, infections characterized by the presence of up to 900 larvae per gram of diaphragm muscle tissue developed without any noticeable symptoms (pigs 1 to 7). With a single exception (pig 7), however, all the pigs that were found to contain 860 or more larvae per gram of diaphragm muscle tissue did show more or less severe symptoms.

While the number of larvae per gram of diaphragm muscle tissue bears in a general way a relation to the estimated size of the infecting dose (table 1), particularly in the case of the lighter infecting doses, this relationship is subject to rather wide variations. For instance, pigs 18 to 23, weighing between 150 to 160 pounds at the time of infec-

tion with the 120,000 larvae each, showed up to 2,700 larvae per gram of diaphragm muscle tissue, while pig 26, weighing 90 pounds at the time of infection with 174,000 larvae, contained only 2,100 larvae per gram of diaphragm muscle tissue. That many larvae may go astray in the course of their migration through the body has already been mentioned in the account of the life cycle of *Trichinella spiralis*. It is probable that other factors, including the host's defense mechanism, may be involved in the degree of the resulting infection.

In the hope of securing more precise information on the symptoms of experimental trichinosis in swine than was afforded by the data already presented, the writer, in collaboration with Underwood and Cross, infected seven pigs with varying doses of trichina larvae. These host animals were under careful observation at the Agricultural Research Center, Beltsville, Md., throughout the period during which the severe symptoms would be expected to manifest themselves, and for some time after this period. During the period of observation, the pigs were carefully scrutinized, temperature, pulse, and respiration rates being taken at frequent intervals and a general physical inspection being made at each observation.

Four pigs weighing 20.45, 20.91, 22.27, and 22.27 kilograms (45, 46, 49, and 49 pounds), respectively, were fed trichinous meat, the number of larvae administered to the individual pigs being 10,000, 15,000, 20,000, and 25,000, respectively. The four pigs were under careful observation for 50 days, 2 days prior to and 48 days following the feeding of the infected meat. During this period the animals were examined on 37 different days, without showing the slightest deviation from the normal. On postmortem examination, 50 days after infection, no macroscopic lesions of any kind were found. The trichina content of these pigs per gram of muscle tissue was estimated by obtaining and digesting 200 grams of muscle tissue taken from different portions of the body, including the diaphragm. The number of trichinae per gram of mixed muscle tissue was 52, 46, 77, and 149, respectively. The weights of these host animals, determined shortly before they were killed, were 37.25, 30.91, 35.91, and 36.82 kilograms (72, 68, 79, and 81 pounds), respectively. Considering the ration fed, the increase in weight was nearly normal.

Three other pigs, weighing 22.73, 22.5, and 19.32 kilograms (50, 49½, and 42½ pounds), respectively, were infected with larger doses of larvae, the doses being 50,000, 75,000, and 100,000 larvae, respectively. These pigs were kept under observation for 83 days, during which they were carefully scrutinized 3 times before and 19 times after infection. The examinations of these host animals were made about 4 to 5 days apart in most instances, except during the second and third weeks of infection, when more frequent observations were

made. Three days after infection, the pigs developed diarrhea. These host animals showed pale or slightly injected mucous membranes at various times. About 18 days after infection, some evidence of poor physical condition began to manifest itself and, 4 days later, the pigs appeared to be "off color" with indefinite symptoms; there was evidence of a slight edema of the eyelids and vulva. Five weeks after infection the pigs appeared normal.

The temperatures of the pigs remained normal except in the case of the pig receiving 75,000 larvae and developing the heaviest infection, as determined later by the number of larvae per gram of mixed muscle tissue. This animal showed a temperature of 105°F., or slightly above or below this on the eighth, eleventh, fifteenth, and forty-first days after infection; occasionally this animal showed a rapid pulse. When these three pigs were killed, 79 days after infection, they were found to contain 840, 1,535, and 1,215 larvae, respectively, per gram of mixed muscle tissue. The weights of these pigs immediately before they were killed were 31.7, 23.41, and 22.04 kilograms (69.75, 51.5, and 48.5 pounds), respectively, indicating a failure to gain weight at a normal rate. It is evident from these data that even careful observations of pigs following experimental infection with large doses of trichinae failed to reveal any symptoms that were definitely suggestive of trichinosis or any other specific disease.

CONTROL OF TRICHINAE IN SWINE

It is evident from the data on the prevalence of trichinae in grain-fed swine that the persistence of these parasites in nearly 1 percent of these host animals is conclusive proof that much still remains to be done to reduce, if not to eliminate altogether, the small residuum of these parasites which, under certain conditions, may be distinctly pathogenic to their porcine hosts. Without minimizing the importance of trichinae to the livestock industry of the United States from the viewpoint of their injuriousness to hogs, the chief importance that attaches to these parasites is their bearing on human health. In the United States, human beings acquire trichinae as a result of eating raw or inadequately cooked pork, the only conclusive exceptions to this statement being a small outbreak of trichinosis in California which was traced to the consumption of jerked bear meat (Meyer, 12), and several sporadic cases traced to bear meat.

Although the evidence presented in this paper shows that the vast majority of the infested swine examined by the digestion method had light or practically negligible infections, the data indicate conclusively that sources of trichina infection exist on farms in the Atlantic seaboard States, the north central States, the Middle West and elsewhere. Among the possible sources of trichina in-

fection on farms in the areas mentioned are the contents of the scrap barrel, offal from hogs butchered on farms and in country slaughterhouses, dead hogs, dogs, cats, and rats which are not properly disposed of and are available to pigs, and are probably eaten by them, particularly when the latter are affected by some nutritional deficiency.

Since the incidence of trichinae in the 6,484 hogs fed on raw garbage was 4.41 percent, nearly five times as great as that in the series of grain-fed hogs, it is safe to conclude that the feeding of uncooked garbage favors the spread of trichinae to swine. Although the bulk of garbage that is fed to swine consists of vegetable matter, raw pork bones with adhering meat, and trimmings containing small portions of swine muscle tissue are also likely to be present. As a small percentage of swine muscle tissue may contain living trichinae, the continued feeding of uncooked garbage is apt to result and does result in the continuation of the vicious cycle of trichinae in a relatively large proportion of such hogs.

As an alternative to the elimination of garbage feeding altogether, cooking of garbage to a temperature sufficient to destroy the vitality of all live trichinae that may be present in pork contained in it is a procedure that should be given careful consideration by garbage-feeding establishments and adopted as an alternative to the feeding of garbage as collected. The data already presented show that out of nearly 2,000 samples of diaphragm muscle tissue obtained from hogs known to have been fed on cooked garbage, only about 0.5 percent were found to be infested with trichinae, and of those so infested nearly 50 percent contained negligibly small numbers of these parasites. Another possibility, more applicable to the farm than to garbage-feeding establishments, is the elimination of meat from feed intended for hogs.

The control of trichinae in swine has been of interest to the United States Government since 1881. As already stated, the earlier investigations on trichinae by scientists of the Bureau of Animal Industry were stimulated largely by the restrictions placed by various foreign governments on the importation of pork from this country. Actually, however, nearly all the pork shipped from the United States to Europe in the last few decades of the nineteenth century was exported in the cured state, and it has been known for a long time that thorough curing is destructive to trichinae. To meet the slurs cast by certain European countries on the United States livestock industry, Dr. Daniel E. Salmon, the first chief of the Bureau of Animal Industry, detailed to Germany Dr. Charles W. Stiles, at that time zoologist of the Bureau, to investigate outbreaks of trichinosis in that country, alleged to have resulted from the consumption

of pork imported from the United States. Dr. Stiles (13) was unable to trace definitely a single case of trichinosis occurring in Germany between the years 1881 and 1898 to pork from the United States. He did, however, trace about one-third of over 6,000 cases of trichinosis that occurred in that country, during the period mentioned, to pork which had been examined microscopically by German inspectors and certified by them as free from trichinae. These facts, elicited by the Bureau of Animal Industry, strengthened the Bureau's position as regards the futility of microscopic inspection of pork as an effective safeguard against human trichinosis, and led to investigations which established the present method of handling the trichina problem under federal meat inspection procedure.

As a result of discoveries by Ransom (10, 14) that trichinae in pork could be destroyed by refrigeration for a continuous period of not less than 20 days at a temperature not higher than 5° F., the establishment by Ransom and Schwartz (15) that the thermal death-point of trichinae is 131° F. (137° F. for official purposes), and finally the work of Ransom, Schwartz, and Raffensperger (16) on a number of practical methods of curing various pork food products customarily eaten without cooking, the following procedures have been adopted.

Fresh pork, and ordinary varieties of cured pork intended to be cooked in the home and elsewhere, are subjected to no treatment or inspection, since no practical treatment to destroy trichinae and no economically practical system of inspection to discover these parasites have as yet been devised. All products containing pork muscle tissue, to be sold as cooked products, are heated or cooked under the supervision of inspectors, according to methods which are known to insure a sufficiently high temperature to destroy in all parts of the meat the vitality of any trichinae that may be present. For all products which are not cooked or heated to a sufficiently high temperature, but which are nevertheless intended to be eaten by the consumer without being cooked, various alternative methods of preparation are prescribed, including the refrigeration procedure already mentioned, smoking, curing, drying, and other processes. All the individual methods prescribed have been shown by careful experimentation to be destructive to the vitality of trichinae.

In addition to the protection thus afforded to consumers of the classes of products mentioned, the Bureau of Animal Industry has called attention at frequent intervals to the danger of acquiring trichinosis as a result of the consumption of raw pork or meat food products containing raw or inadequately cooked or cured pork muscle tissue. Through leaflets, bulletins, press releases, posters, radio broadcasts, and official correspondence with health officers and the public generally, the facts available in the Bureau's files have been

given wide publicity. The statistical information on the prevalence of trichinae in swine in this country has been published repeatedly as a warning to the public that the consumption of raw or inadequately cooked pork may be fraught with serious, if not fatal, consequences. Practically all the constructive measures designed to protect the American public from the danger of acquiring trichinosis originated in the Federal Bureau of Animal Industry.

Recently several writers either stated or implied that the persistence of trichinosis in man, despite the warnings issued by the Bureau of Animal Industry as to the importance of cooking pork as a health safeguard, is evidence that these warnings are not heeded and are, therefore, futile. In the opinion of this writer such a conclusion is erroneous and contrary to a sound public health policy. Thorough cooking of pork in the home and in public eating places is the most effective known weapon against human trichinosis and is entirely practical. A systematic and persistent campaign on the importance of thorough cooking of meat, sponsored by public health agencies, would in all probability reduce the incidence of trichinosis and of nonclinical trichina infections. It is suggested that public health officials and practicing physicians may properly emphasize that the eating of raw or partially cooked meat is an unhygienic habit that may be fraught with unpleasant if not serious consequences, not only as regards trichinae and other parasites transmissible from food animals to man, but also as regards the danger of acquiring infectious diseases.

Since, as already stated, trichinosis and nonclinical trichina infections in human beings in this country are due to the consumption of raw or inadequately cooked pork or inadequately cooked or cured meat food products containing pork muscle tissue, it is evident that the eradication of trichinae from hogs would eliminate trichinosis from human beings. The ultimate eradication of trichinae from hogs in the United States is a problem confronting livestock sanitary officials. Bureau of Animal Industry inspectors engaged in field work and others have emphasized for years the advantages of the swine sanitation system for profitable swine production. Under the sanitation system of swine management, most of the known sources of trichinae are precluded. Livestock sanitarians throughout the United States could, by concerted effort, sharply reduce the prevalence of, and ultimately eradicate, trichinae from swine by educating swine producers on sanitary methods of management.

The eradication of human trichinosis is a problem confronting public health officials primarily with supplementary aid from live stock sanitary officials. Adequate cooking of pork in the home and in public eating places, adequate processing under State or local

meat inspection of meat food products containing pork muscle tissue, if of kinds that are customarily eaten without cooking, and establishment of meat inspection in communities that lack this public service, will help to reduce and ultimately eliminate trichinosis from man. A more comprehensive campaign of education under the auspices of public health workers and educators on the importance of adequate cooking of pork as a health safeguard will do much to reduce the danger of trichinosis to a minimum.

While clinical trichinosis in human beings in the United States is far from being an alarming problem, it is nevertheless a medical problem that should not be neglected, because trichinosis is a serious, painful, and, sometimes, a fatal disease. The definitely known cases of clinical trichinosis in human beings in this country probably do not exceed 5,000 or 6,000. The more or less recent findings on the incidence of trichinae in over 6,000 human cadavers that were necropsied in hospitals in California, the District of Columbia, Massachusetts, Missouri, Minnesota, New York, and elsewhere (table 2) are of greater interest from zoological and statistical standpoints than from a medical standpoint. These data do show, however, that a strikingly large percentage of the cadavers in question contained varying numbers of trichinae, too small, however, in most instances to have had, or been known to have had, any medical significance.

It is obvious from these findings that some individuals intentionally or unwittingly eat pork that has not reached in all of its parts a temperature of 137°F., which is known to be lethal to trichinae. The need of adequate cooking of pork in the home, in restaurants, and elsewhere should be emphasized by public health physicians, nurses, school teachers, and others engaged in medical and educational work. A well-directed campaign of this sort will be productive of constructive results, particularly if coupled with vigilance on the part of public health officers in the regulation of the operation of garbage-feeding establishments on the outskirts of cities and towns in such a manner as to eliminate feeding of garbage containing scraps of uncooked meat.

SUMMARY AND CONCLUSIONS

This paper contains information on the discovery of trichinae in swine and in human beings, the recognition of the pathogenicity of these parasites, their life history, important outbreaks of human trichinosis in Germany due to the consumption of raw pork, the restrictions imposed by various European countries on the importation of pork from the United States, the establishment and abandonment in this country of microscopic inspection of pork intended for export to the countries that imposed these restrictions, and data con-

TABLE 2.—*Recent data on the incidence of trichinae in human cadavers*

Authority and date	Place	Technique of examination	Data reported			Comments
			Number of cadavers examined	Positives found		
				Number	Percentage	
Queen, 1931 (17)	Rochester, N. Y., and Boston, Mass.	Digestion	344 58	59 16	17. 5 27. 6	No history of trichinosis in any of the positives.
Riley and Scheifley, 1934 (18).	Minneapolis, Minn	Press preparation	117	20	17. 9	Subjects not recorded as exhibiting symptoms of trichinosis.
Hinman, 1936 (19)	New Orleans, La	Digestion	200	7	3. 5	All positives light (based on number of larvae); none had symptoms of trichinosis.
McNaught and Anderson, 1936 (20).	San Francisco, Calif	Digestion	200	48	24. 0	No case gave a definite history of trichinosis.
Magath, 1937 (21)	Rochester, Minn	Press preparation	220	17	8. 0	No symptoms definitely suggestive of trichinosis.
Queen, 1937 (see Scheifley, 1938) (24).	Denver, Colo	Digestion	431	70	16. 2	No data available regarding symptoms.
Sawitz, 1937 (22)	New Orleans, La	Digestion	200	10	5. 0	None gave a history of clinical trichinosis.
Evans, 1938 (23)	Cleveland, Ohio	Digestion and press preparation.	100	36	36. 0	Infections light; no information given as to clinical history.
Scheifley, 1938 (24)	Minneapolis and St. Paul, Minn.	Press preparation	118	15	12. 7	Case histories negative for trichinosis.
Walker and Breckenridge, 1938 (25).	Birmingham and Tuscaloosa, Ala.	Digestion	100	33	33. 0	No heavily infected cases; no data as to clinical symptoms.
Pote, 1939 (26)	St. Louis, Mo	Press preparation	1, 060	163	15. 37	No symptoms of trichinosis in positives.
Wright, 1939 (27)	Washington, D. C	Digestion	3, 000	489	16. 3	No data regarding symptoms.
Hood and Olson, 1939 (28).	Chicago, Ill	Digestion and press preparation.	100	16	16	No data regarding symptoms.

cerning trichinae in about 8,000,000 hogs from which samples were examined up to 1906. In addition, information is given on recent findings on the incidence of trichinae in hogs, as follows:

Out of 6,622 samples of pork obtained from grain-fed hogs originating in various hog-growing centers of the United States, only 60 (0.91 percent) were found to be infected with trichinae. Out of 6,484 samples of pork obtained from hogs fed on garbage as collected, 286 (4.41 percent) were found to be infected, while out of 1,987 samples of pork obtained from hogs that had been fed on cooked garbage, only 11 (0.55 percent) were infected; the samples from the garbage-fed hogs, like those from the grain-fed hogs, were examined by the digestion method. Additional data involving the examination of a total of 13,162 diaphragms from as many grain-fed hogs and 10,500 diaphragms from as many hogs fed on garbage as collected show an incidence of trichinae in the latter six times that in the former.

The logical inference from these data is that the feeding of uncooked garbage favors the spread of trichina infection among hogs, and that cooking of garbage is an effective method of sharply reducing the incidence of trichinae in this class of hogs.

An analysis of the data, with reference to the samples of pork that contained trichinae, shows that the degree of infection with these parasites was rather light, and that if the samples in question had been examined microscopically, a large proportion of the positives, discovered by the digestion technique, would have been overlooked.

Data obtained as a result of experimental infection of pigs with varying doses of trichina larvae, show that the host animals in question showed no readily recognizable symptoms when the resulting infection was characterized by the presence of less than 800 to 900 larvae per gram of diaphragm muscle tissue. Pigs with heavier infections did show clinical symptoms during the active stage of the disease, including digestive disturbances, muscular stiffness, inappetence, fever, edema, and other conditions, all the symptoms not being shown by each animal experimentally infected with relatively large doses of larvae, and the symptoms as a whole not being diagnostic of any particular swine disease.

The evidence presented in this paper shows that swine may succumb to heavy infections with trichinae, death occurring as early as 7 to 10 days after infection.

Considering the minimum number of trichinae per gram of diaphragm muscle tissue associated with clinical symptoms during the active stage of the disease, only 1 out of the 357 trichina-infested hogs that came to light as a result of digesting samples from 15,333 hogs,

had an infection sufficient to have been productive of symptoms, the infections in the remaining 356 positive hogs being apparently of the nonclinical type, as far as can be judged by the data presented in this paper.

The control of trichina infection in swine and the ultimate eradication of this disease from these host animals involve improved livestock sanitation on farms, the elimination of meat from the scrap barrel, the control of rats, burning or deep burial in quicklime of animals that die on the farm, and an adequate diet for swine to prevent the development of a capricious appetite. Since the feeding to hogs of garbage as collected appears to be the main source of trichina infection, garbage fed to swine should be cooked to kill trichinae that may be present in scraps of pork in the garbage. Garbage that is definitely known to contain no meat or bones need not be cooked. The sale, by cities and towns, of uncooked garbage for the feeding of hogs is a dangerous procedure and should be discontinued in the interest of the livestock industry and as a public health measure.

Since human beings acquire trichinosis as a result of eating raw or inadequately cooked pork or inadequately cooked or processed meat food products containing pork muscle tissue, a comprehensive campaign to educate the public regarding the danger of acquiring trichinosis from the sources mentioned should be undertaken by public health officials, teachers, nurses, and others engaged in educational work. Public health officials should regulate the operation of garbage-feeding establishments so as to prohibit the feeding to swine of garbage that has not been properly cooked, unless the garbage is known not to contain meat scraps and bones.

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CLOSING THE GAP AT TEPE GAWRA [1]

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[With 12 plates]

In October 1927, I had the experience of starting excavations on a hitherto unknown ancient mound. The place was Tepe Gawra, "The Great Mound," in the Turkomanized dialect of the local Kurds. It is situated 14 miles north of modern Mosul, in northern Iraq, and 2 miles east of the remains of Dûr Sharrukin, one of the capitals of old Assyria. The site had been chosen a few months earlier, out of several hundred mounds surveyed, as the one most likely to constitute a guide through prehistoric Assyria. Our sole basis for this optimistic estimate was the nature of the potsherds found on the slopes and at the foot of Tepe Gawra. The name itself could not be regarded as an indication of expected contents; for it was due entirely to appearances—the mound stood 70 feet above the surrounding plain, and this circumstance made it a "great" landmark.

The first campaign was conducted by a staff of three, which included a European architect just out of school and a 13-year-old son of a colleague at the University of Pennsylvania. It lasted 2 weeks because at the end of that period our budget of $500 had been exhausted. But the results of this brief preliminary dig, for which the American Schools of Oriental Research and the Dropsie College of Philadelphia were sponsors, were sufficiently impressive to justify a systematic exploration which began in January 1931, with the Museum of the University of Pennsylvania as an added partner in the undertaking. The successive campaigns which followed have been directed alternately by me and by Charles Bache, a former assistant. I had the good fortune of being out in the field in the season of 1936–37, and the latest campaign was opened by Mr. Bache, with only a quarter of the mound's original height remaining (pl. 1), in October 1937, exactly 10 years after Tepe Gawra had first been brought to the attention of the archeological world.

Ten years is not a long time in the necessarily slow process of scientific excavation. Yet Tepe Gawra, which in 1927 could not be found

[1] Reprinted by permission from Asia, vol. 38, No. 9, September 1938.

even on the larger military maps, is today a common term in numerous technical publications and not a stranger to the lay reader. A recent popular history of Assyria, published in Germany, has introduced the designation "Tepe Gawra culture" for one of the significant stages of prehistoric Mesopotamia. Such a rapid rise to prominence has to be well founded. The reason indeed is not far to seek. To put it in a single sentence, Gawra furnishes the longest continuous record of superimposed occupations known to science. What is more, the latest of these settlements was abandoned 3,500 years ago, and only the first six building levels, counting from the top, date from after 3000 B. C. The rest, more than 90 feet out of a total height of 104 feet of occupational deposits, witness for us the fourth and fifth millennia B. C., periods that are little known or entirely unknown except for the testimony of this mound. No other site can be said to duplicate, or even approach, this notable record. Ancient Nineveh was settled probably as early as Gawra and attained to its greatest fame in Assyrian times when the latter mound was already a long-abandoned *tell*; but Nineveh suffered from lengthy periods of desertion, so that her testimony is not continuous. Famed Uruk, in southern Mesopotamia, started out long after Gawra, as did all the other sites in the south, even though it was to remain inhabited down to the first millennium B. C. Moreover, the testimony of Uruk has to be pieced together from the remains of several distinct areas; it is not neatly stratified in a single layered deposit as is Gawra. Here alone is the record unified and uninterrupted. Of the approximately 7,000 years which separate the end of the neolithic age from our own times, Gawra covers the first 3,500—a cultural contribution wholly without parallel.[2]

Today we can estimate the significance of the mound as a whole, although one more season is required before the expedition to Tepe Gawra will have completed its original task. That the results can be viewed at this time in their correct perspective is due primarily to the work of the past season, which served to close the gap between the lowest strata, reached in a trial trench in the spring of 1937, and the upper levels, whose systematic removal from the top down has been going on since 1931 (pl. 2). We are thus in a position not only to survey the entire contents of the site, with special emphasis on the accessions of the past season, but to sense as well their far-reaching cultural implications. But, before such a summary review is attempted, it is in order to recall the outstanding results of the previous campaigns.

The three uppermost levels contained material remains of the Hurrians, a leading factor in the extremely complicated history of the second millennium B. C. It is fairly characteristic of the im-

[2] See Smithsonian Ann. Rep. for 1933, pp. 415–427, 1934.

mense antiquity of Tepe Gawra that the mound ends with a civilization which modern archeology has barely begun to appreciate. Levels IV–V represent the Old Assyrian period, and levels VI–VII take us back to the Early Dynastic age, at the beginning of the third millennium. All the remaining strata are predynastic and hence prehistoric. In the southern lands of Sumer and Akkad excavations have established the presence of three main predynastic civilizations, the first and latest of which is called Jemdet Nasr, the second Uruk, and the third and earliest Obeid, the names being derived from the respective significant sites. It follows that man first settled in those areas in Obeid times, when the marshlands of Lower Mesopotamia had at length become suitable for occupation. It should be pointed out, however, that general designations of this sort do not necessarily imply cultural or ethnic uniformity. As a matter of fact, the Jemdet Nasr and Uruk periods were characterized even in the south by the presence of several disparate elements, each of which can be traced by its own distinctive contribution to the civilization of the age in question. In the north, where Nineveh and Gawra were important contemporary centers, the situation was further complicated by the circumstance that other independent groups, which had never reached Kish or Ur or Uruk, helped to shape the local civilizations. We know, for instance, that Gawra VIII–XI flourished in Jemdet Nasr and Uruk times; but, while cultural contacts with the south were numerous and manifest, there was here also an important independent residue. These Gawra levels show an exclusive use of the stamp seal, as against the cylinder seal of the Early Dynastic period. In Jemdet Nasr and Uruk proper the cylinder seal is used also in late predynastic times, alongside the stamp. Moreover, the stamps of Gawra differ basically from those in the south in spirit and execution, so much so that the respective craftsmen must have belonged to different racial groups.

The temple architecture of Gawra VIII–XI is of outstanding significance. In each of these four levels, not to mention a number of sublevels, the design is essentially the same: a severely symmetrical structure with the entrance on the narrow side and a podium in the center of the long cult chamber. The walls are decorated with double-recessed outside niches, regularly spaced. The shrines of contemporary Uruk bear only a general and superficial resemblance to this long succession of Gawra temples.

Gawra XI–A was dominated by a unique Round House, which combined the features of a temple and a citadel. With Gawra XII we come down to an age which was given over in the south to the Obeid civilization. If it were not, however, for the discoveries in the north, this interesting period could not be seen in its proper light.

It should be remembered that at this stage writing had yet to be invented and the knowledge of metallurgy was but inchoate. The marshlands of the south were being rendered habitable by slow and laborious effort, and the first dwellings were flimsy mud huts. Since these settlements of the Obeid age were obviously the oldest in that area, it was assumed at first that the Obeid civilization was the earliest in the whole of Mesopotamia and that it represented a primitive stage in the progress of man. Inasmuch as the characteristic pottery of the time was painted, and bore some resemblance to other painted wares strewn over vast sections of the East, the Painted Pottery People became the carriers of the oldest civilization of Asia.

All these misconceptions have been changed by the results of Mr. Mallowan's excavations at Arpachiya and particularly by those of our two most recent seasons at Gawra. The Obeid culture is preceded by at least two still older civilizations known in the north, where human occupation was possible much earlier than in the southern alluvium. The term "Painted Pottery People" is meaningless as an ethnic designation; for there was more than one early civilization specializing in painted wares, each originating perhaps with a different ethnic group. Lastly, far from being primitive, the Obeid age was highly advanced and elaborate, especially with regard to architecture, glyptics, and pottery. The impressive acropolis of Gawra XIII, with its beautifully arranged temples displaying red-painted walls and floors, and utilizing deep niches, piers, and pilasters for functional as well as decorative purposes, is sophisticated to an anachronistic degree. The ground plan of such a temple [3] presupposes a long period of evolution. It differs from the basic design of the shrines found in Gawra VIII–XI in that the entrance is on one of the long sides, near the corner, the worshiper having to make a turn of 90 degrees in order to face the inner sanctum. In this respect the temple of Gawra XIII was not unlike the later sanctuaries of the Early Dynastic age, as known from Khafajeh and Tell Asmar, in the neighborhood of Baghdad, and the still later shrines of historic Assyria. It is worth stressing that such divergencies in architectural design are a positive indication of corresponding cultural and ethnic differences. In other words, the civilization of Gawra VIII–XI was not related directly to the culture of contemporary Ur or Uruk; and it differed notably from the civilization of Obeid times. This is a surprising commentary on the allegedly simple conditions of prehistoric life.

To carry still further the absorbing study of the Obeid period was one of the main tasks of the campaign which began in October

[3] See Asia, December 1937, p. 836.

1937. Another problem was to determine the total number of independent building levels preserved at Gawra. The preceding campaign had reached virgin soil, but that was accomplished by means of a small sounding sunk down from the eastern edge, and not in the regular excavation from the top. The side cut revealed six pre-Obeid levels of the so-called "Halaf" period, with a still earlier, purely neolithic, stratum resting on virgin soil. Simultaneously, the systematic removal of layers in the main dig had brought us down to level XVI. But this stratum was still too late to dovetail with the top layer of the sounding. Definite correspondence had to be sought in level XVII or below that. Until the two excavations had been linked by material remains, there was no means of determining the full length of the Obeid occupation and the termination of the preceding Halaf culture, the fourth long stage of prehistoric Mesopotamia.[4]

The season of 1937–38 brought the solutions to these questions and contributed additional information that was altogether unexpected. I shall outline the principal results in the remainder of this account, with the aid of illustrations and field notes kindly submitted to me by Arthur J. Tobler, the assistant director of the expedition.

The Obeid age, to retain this name for want of a more comprehensive term, proves to have lasted at Gawra from the beginning of level XIX to the end of level XII. This long series of substantial settlements must have spread over a long period of time. While it is impossible to assign absolute dates to prehistoric periods, the span between the middle of the fifth millennium and the first quarter of the fourth should be safe enough for purposes of general orientation. The accompanying material remains have their own peculiar eloquence at a time when the introduction of written records was still some centuries away.

The period as a whole, the third in the order of remoteness from the Early Dynastic age, has now definite boundaries at either end. It was preceded by the Halaf civilization, which was predominant up to the end of Gawra XX; and it was followed by the northern counterpart of the Uruk culture beginning with Gawra XI–A. Its own sway extended thus over eight occupations. The guiding and unifying element is furnished by pottery. There are certain characteristic features of ware and decoration which persist throughout the eight superimposed settlements, but are not found either before or after. Other features come up and vanish within the main period, without affecting all of its stages.

A common shape is a deep bowl with vertically arranged decoration in black or plum-red (pl. 5, fig. 2). The designs consist of various

[4] See now The beginning of civilization in Mesopotamia, Journ. Amer. Oriental Soc., vol. 59, No. 4, suppl., pp. 17–31, 1939.

geometric patterns, but naturalistic representations, especially of birds, are not infrequent, and human figures are also present occasionally. On one bowl, painted upside down, we find a curiously stylized picture of a human being dancing (pl. 6, fig. 2). From level XVII come fragments of beakers decorated near the rim with rows of long-necked birds, precisely as on the celebrated tumblers from earliest Susa. This correspondence should settle once and for all the protracted dispute concerning the relative age of Susa I. We know now that the magnificent fabrics from the lowest deposits of Susa date from about the same time as early Obeid, and are consequently later than the remains of the Halaf period.

Fairly common are globular jars with long and rather narrow necks and curvilinear ornamentation (pl. 3, fig. 2). A novel shape is provided by a number of boat-shaped vessels displaying a variety of geometric designs (pl. 5, fig. 1). Most interesting, however, are the tortoise-shaped vessels with long, obliquely set necks and separate, narrow openings in the sharply carinated bodies. They are profusely decorated (pl. 4, fig. 1). Other pottery products include curved nails, which are so intimately associated with the Obeid sites of the south (pl. 4, fig. 2), painted figurines of the mother goddess (pl. 6, fig. 1) and, finally, a rattle and a toy animal figurine found in a child's grave from level XVII (pl. 7, fig. 1).

Perhaps this is a good time to comment on the appropriateness of the designation "Obeid" which we have been using for the entire period extending from Gawra XIX to XII. It commends itself by the inner unity of some of its ceramic products, and by the further relationship to significant elements of the Obeid deposits in southern Mesopotamia. The main objection to this term, however, when applied to Gawra and the north in general, is the implied suggestion that the correspondence between north and south was complete in substance as it was in time. This is not the case by any means. Gawra had been settled, as was explained above, long before human occupation was possible in the south. A strongly individualized civilization, termed "Halaf," had been displaced by the inhabitants of Gawra XIX–XII. Those predecessors did not disappear without leaving tangible traces of their own achievements, and pottery had been one of the glories of the Halafians. It follows that motifs of Halaf times were bound to survive and carry over into the Obeid period. As a matter of fact, Halafian pottery commingles with the new wares all the way up to Gawra XV. Nor is this the only heterogeneous ingredient. Fully as early as Obeid was the civilization named after Samarra, 80 miles north of Baghdad. Now Samarra pottery differs basically from Halaf wares, but exhibits numerous connections with Obeid fabrics, so much so that the latter may be regarded as a southern specialization of Samarra. If we were to make minute distinctions, we should

link Gawra XIX–XV with the Samarra province, adding that demonstrable contacts with the south are not found as a rule until later on, specifically Gawra XIII. For our present purposes it will suffice to state that, after the decline of the Halaf culture, Gawra was dominated by a mixed Halaf-Samarra civilization, which gave way in turn to one with a pronounced Obeid tendency. Toward the end of the lengthy and syncretistic period represented by Gawra XIX–XII we witness the intrusion of yet another element, this time from the Iranian highlands. These manifold changes and combinations were taking place 6,000 years ago. The comforting thought that early civilizations were uniform and local is thus driven out by the composite picture which modern archeology has succeeded in reconstructing.

Our conclusions based on the examination of pottery are borne out by the study of contemporary architectural remains. In this respect in particular, the early Obeid levels of Gawra have much to offer. As early as level XIX we get a surprisingly clear plan of a house with an enclosed courtyard in front of it (pl. 8, fig. 2). By the side of this secular building, we find in the same level the remains of a temple, the oldest religious structure known to man so far. In later, historic times temple areas were not to be used over for private dwellings. This type of taboo proves now to have existed also in remote prehistoric periods. For on the ruins of the shrine from Gawra XIX there was erected, in the succeeding level, a temple of closely similar design (pl. 7, fig. 2). It is exceedingly interesting that these temples of XIX–XVIII recall by their podia and entrances from the short side, not the units of the Gawra XIII acropolis but the series of shrines of Gawra XI–VIII. In other words, there appears to be a cultural relationship between the builders of early Obeid and those of Uruk times; the intervening structures of late Obeid times point, on the other hand, to a different and unrelated tradition. In the face of these facts, one hesitates to guess at the nature of the transformation that was responsible for the revolutionary developments embodied in the acropolis of Gawra XIII. Such an upheaval could be brought about only by new ethnic forces.

Gawra XVII poses a problem no less acute. Here were uncovered the remains of a *tholos*, or a circular building which originally may have resembled a beehive dwelling (pl. 8, fig. 1). Now, prehistoric *tholoi* are known otherwise only from the Halaf levels of Arpachiya, near Nineveh. At Gawra, pure Halaf levels do not occur after stratum XX. Thus architecture confirms the evidence of pottery in characterizing the early Obeid deposits of Gawra as composed of Obeid-Samarra as well as Halaf elements.

Burials yielded many of the smaller objects recovered during the season, including the best specimens of pottery. In fact, one of the graves appears to have been a potter's burial; for the funerary

furnishings include a palette for mixing paints and a few pottery smoothers (pl. 10, fig. 2). The bodies, mostly from the cemetery of level XVIII, were placed, with but one exception, in a contracted position (pl. 11), and this is true of the woman who had been placed in her grave holding her child in her right arm. The tiny bones of the infant are barely visible in the photograph (pl. 10, fig. 1). The single extended burial was found in level XVII (pl. 9, fig. 2). Since the position of the body is almost invariably a distinctive racial custom, it appears that this one departure represents a stranger, very likely from the south. Besides pottery, the commonest grave furnishings were pendants and beads (pl. 9, fig. 1) of limestone, shell, and obsidian.

Numerous remains of the later Obeid period at Gawra were found in a well sunk down from level XIV. By far the most valuable of these finds were seal impressions on clay, which came up literally in basketfuls. Seals afford a representative picture of contemporary art, and we can hardly learn too much about the art of a remote prehistoric period. Of special interest among the finds from the well is the skull of a *saluki*, or oriental gazelle hound (pl. 12, fig. 2). This swift and graceful breed of hunting dog is to this very day a favorite with the Kurds and Arabs, to whom any other kind of dog is the uncleanest of animals. The breeding of salukis proves to have been a very ancient sport indeed. As far back as Gawra XVI this hound was depicted on seals, together with the animals which he was used to pursue (pl. 12, fig. 1).

Level XX brings us down to a true Halaf settlement. This fact is established by the pottery of the stratum, and by its characteristic pendants, some of which bear the design of the swastika, obviously an ancient and purely oriental symbol (pl. 3, fig. 1). Identical remains were uncovered in the season of 1936–37, in the side cut at the eastern edge of the mound. Like the levels in the cut, Gawra XX contains no pottery of the Obeid-Samarra type. It follows that the twentieth stratum corresponds to the top layer of the sounding. We have thus at last a correct count of the total number of building levels which Gawra had stored up for modern archeology. Adding the 5 other Halaf layers revealed in the sounding, and the one underlying pre-Halafian deposit, to the 20 occupations sliced down from the top of the mound, we obtain the astounding figure of 26, which represents so many distinct stages in the progress of prehistoric and early historic man.

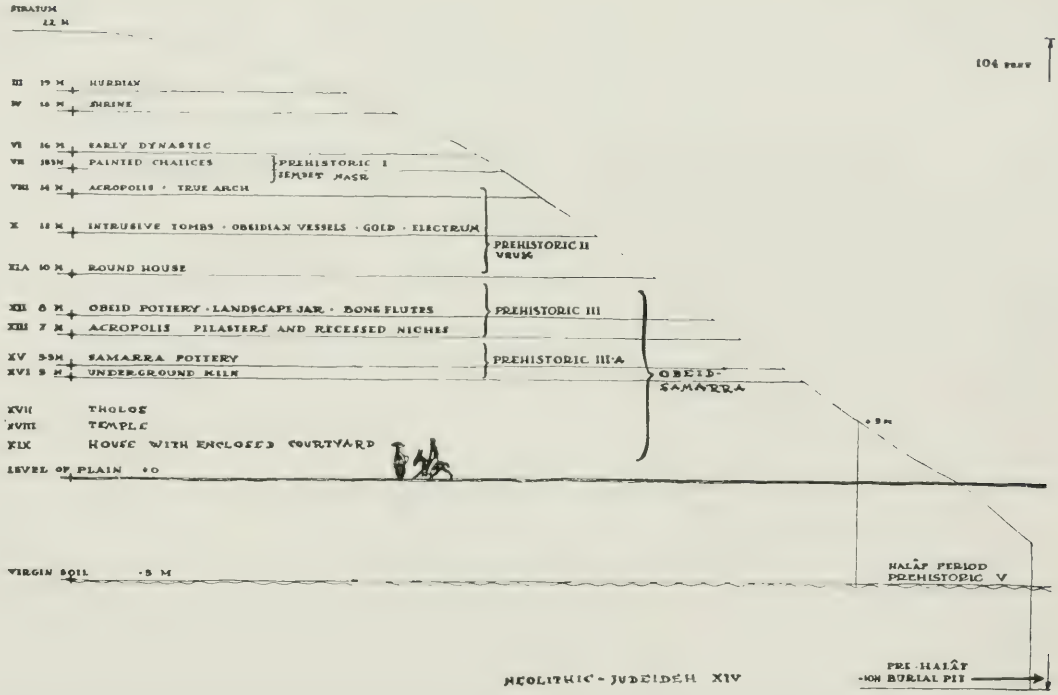
The long ascent had begun with a neolithic settlement, which used a brittle orange ware with wavy red decoration, such as has been found also in the fourteenth stratum of Judeideh, in northern Syria. The first inhabitants of Gawra were thus a group that

had spread from the shores of the Mediterranean to the valley of the Tigris, a remarkable expanse for neolithic times. From that time on, Gawra managed to attract all the important early civilizations now known to Eastern Asia: the Halafian, Obeid-Samarra, the northern phases of the Uruk, Jemdet Nasr, and Early Dynastic cultures, and representatives of Akkadian, Old Assyrian, and Hurrian times. Here the story breaks off, because the conical mound had grown too tall and limited for practical occupation. And well it might break off at this point. From here on, hundreds of scattered mounds and tens of thousands of inscriptions take up the tale. The middle of the second millennium B. C. is a comparatively modern period in the light of today. Nor are the preceding millennia so obscure now as they once were. A brooding Sargon may have pondered over the secrets buried in Gawra, as he viewed the mound from his palace in nearby Dûr Sharrukin. Shepherds watching their flocks from this tall vantage point may have mused drowsily about the treasures within. Today these treasures are no longer imaginary. Archeology has rescued them from their obscurity and turned them into so many milestones of ancient times. But the essential mystery of it all remains undiminished.



TEPE GAWRA, IN THE FALL OF 1937, WAS ONLY ONE QUARTER OF ITS ORIGINAL HEIGHT OF 70 FEET.

The 20 strata above the plain and 6 below cover the first 3,500 years of the period, approximately 7,000 years, from the end of the Neolithic age to the present



SCHEMATIC CROSS SECTION THROUGH TEPE GAWRA, DRAWN TO SCALE BY ALFRED BENDINER.



1. A SWASTIKA, OBVIOUSLY AN ANCIENT AND PURELY ORIENTAL SYMBOL, IS THE DESIGN ON A PENDANT FROM LEVEL XX.



2. JAR OF THE OBEID PERIOD FROM LEVEL XVIII, TEPE GAWRA.



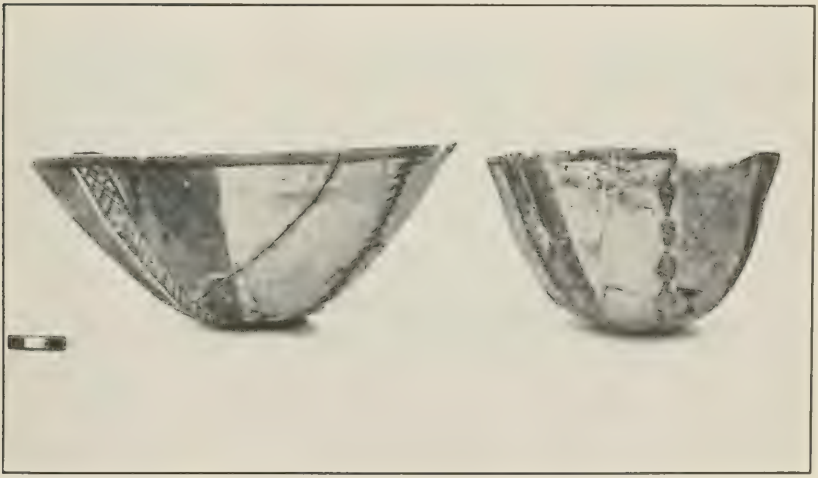
1. JAR OF THE OBEID PERIOD FROM LEVEL XVIII, TEPE GAWRA.



2. TERRA COTTA PEGS OF THE OBEID PERIOD FROM LEVEL XVII, TEPE GAWRA.



1. BOWL OF THE OBEID PERIOD FROM LEVEL XVIII, TEPE GAWRA.



2. TWO TYPICAL BOWLS OF THE OBEID PERIOD: LEFT, FROM LEVEL XVII; RIGHT, FROM LEVEL XIX, TEPE GAWRA.



1. A PAINTED FIGURINE OF THE MOTHER GODDESS, OBEID PERIOD. FROM LEVEL XVII, TEPE GAWRA.



2. A BOWL DECORATED UPSIDE DOWN WITH A STYLIZED FIGURE OF A DANCER. OBEID PERIOD, TEPE GAWRA.



1. LEFT, RATTLE, AND RIGHT, TOY ANIMAL FOUND IN A CHILD'S GRAVE IN LEVEL XVII, TEPE GAWRA.



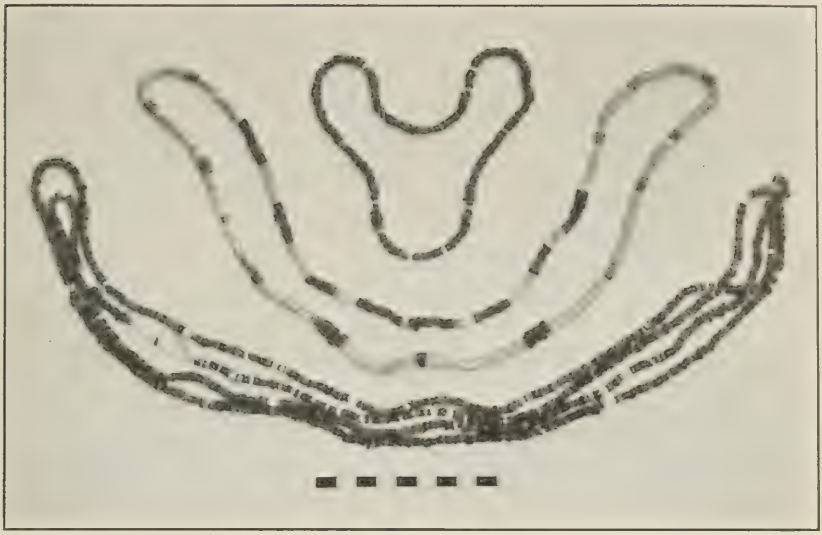
2. LEVEL XVIII REVEALED A TEMPLE WITH FEATURES WHICH HAD APPEARED IN HIGHER LEVELS OF MUCH LATER DATE: TEPE GAWRA.



1. LEVEL XVII OF TEPE GAWRA POSED A PROBLEM WITH THE DISCOVERY OF A "THOLOS" WHICH ORIGINALLY MAY HAVE RESEMBLED A BEEHIVE DWELLING—FOR PREHISTORIC THOLOI ARE KNOWN OTHERWISE ONLY FROM THE HALAF LEVELS OF ARPACHIYA.



2. A SURPRISINGLY CLEAR PLAN OF A HOUSE WITH AN ENCLOSED COURTYARD IN FRONT OF IT, FROM LEVEL XIX, TEPE GAWRA.



1. BEADS FROM A TEPE GAWRA GRAVE, LEVEL XVIII.



2. A SINGLE EXTENDED BURIAL, FOUND IN LEVEL XVII; IT APPEARS THAT THIS ONE DEPARTURE FROM A DISTINCTIVE RACIAL CUSTOM REPRESENTS A STRANGER.



1. BODY OF A WOMAN WITH AN INFANT ON HER RIGHT ARM, FROM A TEPE GAWRA GRAVE, LEVEL XVIII; BODIES WERE PLACED, WITH BUT ONE EXCEPTION (SEE PL. 9, FIG. 2), IN A CONTRACTED POSITION.



2. A PALETTE FOR MIXING PAINTS AND A FEW POTTERY SMOOTHERS FROM A TEPE GAWRA GRAVE.



BODY FROM TEPE GAWRA GRAVE, LEVEL XVIII, SHOWING BURIAL IN A CONTRACTED POSITION.



1. A Seal Depicting Several Hounds, From Level XVI.



2. The Skull of a Gazelle Hound Found in a Well Sunk Down From Level XIV.

SUN WORSHIP[1]

By Herbert J. Spinden
The Brooklyn Museum

[With 6 plates]

The first men, the first really intelligent men, advanced toward knowledge of the world they lived in by remembering their experiences, especially such experiences as normally were repeated in nature. These recurrent events became the facts of life, and for these facts they found words. And among the greatest facts of life were the alternation of day and night, of summer and winter, which inevitably men learned to link with a certain bright thing coming and going in the sky in an orderly and predictable way.

But I do not think that sun worship was the first religious impulse of man newly awakened to intelligence and with a growing means of communicating deeds, inferences, and emotions in articulated speech. I think that much which we call religion and much which we call art sprang from an assumption that reality is at once spiritual and physical—that everything in the world parallels an apparent duality of mind and body in man himself. Now human beings are gregarious animals with a social life fed by interacting personalities. Leadership and followership are responses to a psychology which makes this human herd assume a functional status as a superorganism. When an old trusted leader lies inert, there always has been the question whether the spiritual double of his quiet body might not continue to exist and retain power. And since men cannot be sure, they bury the corpse and placate the ghost. At any rate purposeful burial is the first archeological evidence of religious emotion. Also there are today numerous human societies who believe that the universe is animate and that ghosts of the dead inhabit animals and plants, stones, clouds, and streams, even stars and the greater luminaries of heaven.

Religion arose, it seems to me, in the effort to use the souls of the dead for the benefit of the living. Art arose, it seems to me, as a vehicle of magic, of flattery and coercion over immaterial forces. To be sure, both spread far beyond these first intentions. But while pur-

[1] The eighth Arthur Lecture, under the auspices of the Smithsonian Institution, February 21, 1939.

poseful burials and objects of magical art have been common enough since modern man appeared on earth some 25,000 years ago, more or less, obvious references to the sun are relatively recent. No Aurignacian artist hit upon the device of sun representation as a thaumaturgical means of hastening the end of the ice age.

ANCIENT AND RECENT SUN SYMBOLS

Disks of bone and stone, plain or marked with internal or external rays, are found but rarely in Upper Paleolithic and Mesolithic deposits, and in no case where they do occur can they be linked safely with a cult of the sun. Nevertheless on the subsequent Neolithic horizon similar but more richly varied devices, commonly explained as sun symbols, are found around the world. They are met with as pictographs and petroglyphs in regions where agriculture and the higher arts never have been practiced and among retarded tribes whose culture never has risen above the hunting plane. In other

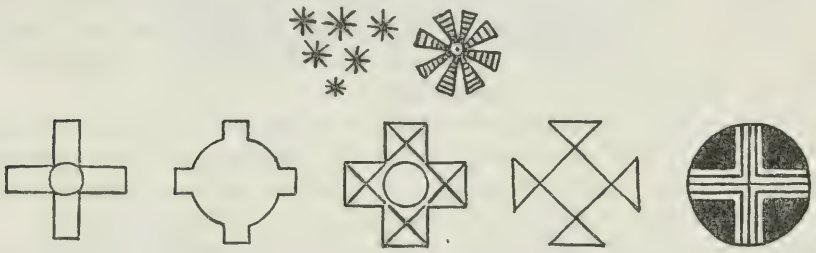


FIGURE 1.—Sun, stars, and cosmic symbols from the Chalcolithic art of western Asia. These symbols, with others, lay the ground for the first writing.

regions, both in the Old and New World, where man uses tamed plants and animals for food and where ceramic and textile arts flourish, the same motives are still further elaborated with considerable evidence of special evolutions. What is the answer? Did these ceremonial figures arise spontaneously and diffuse from one or several centers? Are they true evidences of sun worship?

Some of the simpler sun pictures, such as circles fringed with rays, and circles marked with crosses, are still in use among primitive peoples of both hemispheres who do not hesitate to explain them fully to ethnologists. Others in more complicated forms, but with beginnings as simple, intergrade in richly documented art of the past or the present. Still others enter into the ancient construction of hieroglyphic writing belonging to apparently independent systems, such as the Cuneiform and the Egyptian, the Chinese, and the Mayan. A last group expresses the expanding knowledge and terminology of astronomy with attempts to figure not only the sun, moon, and stars, but also concepts of the earth and the universe.

So much that is fanciful or uncertain has been published concerning the migration of sacred symbols that a rule may be drawn wisely: when a symbol is a valid representation of the sun or other celestial body, it is open to independent reinvention. Nevertheless, examination of the early development of sun cults, in the general regions where the most ancient civilizations resting on agriculture arose in the Old World and the New, certainly indicates diffusion for the higher and more artistic concepts, albeit combined with closely parallel reinventions.

BIRDS AND ANIMALS OF THE SUN

The association of birds and animals with the sun is found around the world in myths and pictures. Several explanations are given, but in each case it is easily seen how the same thought might have been reached by different peoples.

Once the sun is accepted as a god, or the sky as the residence of gods,

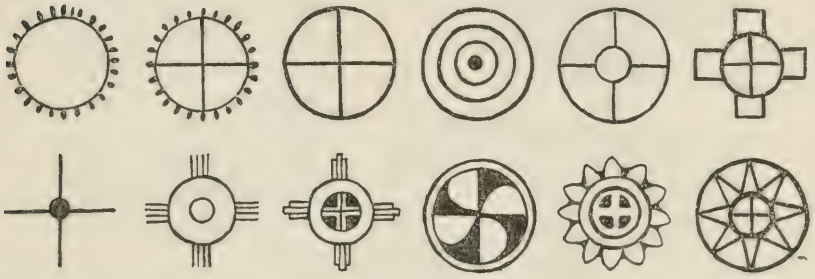


FIGURE 2.—Sun symbols and cosmic symbols of the Mound Builders, painted on pottery, executed on copper and shell gorgets, etc. The sun gives rise to the concept of the four directions, and the four directions furnishes a pattern for the world.

high-flying birds such as hawks and eagles become appropriate messengers. In Egypt the falcon, called Horus, was a sun god ever alert to protect the pharaoh as a soaring, pouncing bird of prey. Homer calls the hawk "the swift messenger of Phoebus." The same thought presented itself to the observant red man. Francis La Flesche explains that the hawk is the tribal emblem of the Osage Indians and of it he writes: "Accordingly those men of ancient days gave to their sacred emblem the hawk, child of the Sun and the Moon, a shrine that was to typify not only the earth, but the space between the earth and the sky; the vast dome of blue wherein move singly or in groups all the celestial bodies." He records three "little songs of the Sun," saying that they refer to the birth of the hawk.

We also find the hawk associated with the sun in Peru. Sarmiento de Gamboa says the Incas regarded falcons as their guardian spirits. These were called *inti*, and since they invaded the realm of the sun, their name was transferred to that luminary.

In Europe and northern Asia during the Bronze and Iron Ages the duck, the goose, and the swan were considered birds of the sun because of their seasonal migrations. That is, they seemed to lead the sun northward for the summer and southward for the winter. The combination of these birds with sun symbols is seen in patterns which become so conventionalized that in their later stages only the bird heads are retained to reveal the meaning. In eastern Asia the cock is associated with the sun by reason of his crowing before the dawn, and in the decorative art of tribes living along the Amur River this domestic fowl is the most conspicuous single subject. In America the duck, at least, was characteristically associated with water rather than with the sun, and there was no pre-Columbian equivalent of the cock.

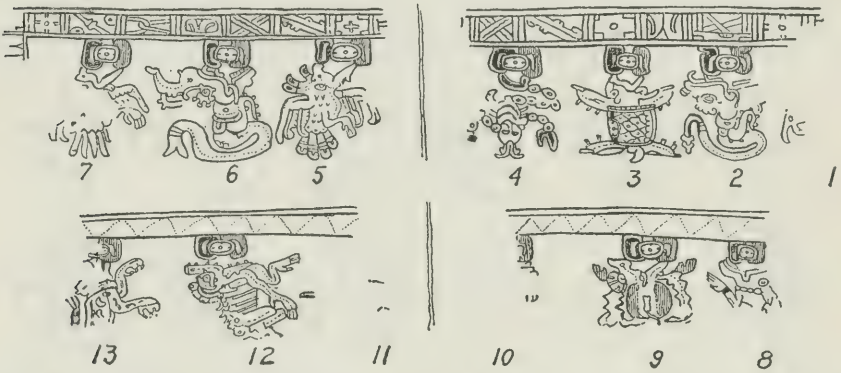


FIGURE 3.—The 13-part zodiac of the Mayas as given in the Codex Peresianus. Each animal is associated with a period of 28 days, 13 of these making a 364-day astrological year. The first five signs are definitely associated with the rainy season, and in agreement with this we know that the Pleiades formed the rattles of the Serpent (2) and that the Turtle (3) was in Gemini.

By far the more important source of bird and animal association with the sun takes place by means of the stars. There is the track of the sun, moon, and planets among the stars which we call the zodiac. To be sure, the sun on rising seems to erase this track, but it can always be caught just before sunrise or just after sunset in the phenomena known as heliacal risings and heliacal settings. Now, all mankind has one thing in common—the lowest peoples join with the highest in constructing out of the stars the creatures and things which they know on earth. Actually, there is nothing more complicated about this than giving names to familiar hills and streams. At any rate here is a game of imaginative art at which all peoples can and do play with great diversity in the results. In consequence, those star groups close to the sun lead to association of the animals

after which they are named with the sun. In classical lands we have the Bull, the Lion, the Scorpion, the Ram, the Crab, etc., while in Tibet or China the list changes. Perhaps the formal 12-part zodiac is one story in the Old World—with an earlier chapter dealing with star groups independently decided upon in different regions. Certainly the Mayas of Central America developed for themselves a



FIGURE 4.—Human sacrifice made to the sun by the Mixteca. Below, Lord Thirteen Deer is sacrificed by Lord Nine House. The eagle and the turtle carry hearts and blood to the thirsty sun god.

different 13-part zodiac, using the same stars, to be sure, but constructing them into different creatures. There is a picture of this New World zodiac in the Codex Peresianus from which it appears that every 28 days the sun enters the mouth of a different zodiacal animal. The Scorpion sign alone is common to the Babylonian system and the Mayan but curiously enough falling on opposite sides of the sky—that is, the Mayan Scorpion is the Babylonian Crab.

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Among the Central American nations sun animals originating in the zodiac include the Eagle, the Turtle, the Deer, the Bat, the Jaguar, etc., some being more important than others. The Jaguar is, indeed, the most important sun animal from Mexico to Peru; perhaps it would be closer to say that the Jaguar is the sun. The Eagle comes next, and it may be that the importance of this bird is partly derived from other associations than the zodiac. In a Mixtec manuscript we see the Eagle and the Turtle acting as messengers in delivering the blood and hearts of sacrificial victims to the sun. The Deer is pictured as the sun-bearer, and the Rabbit carries the moon or resides within it.

WHAT SUN MYTHS TELL US

There are other associations involving men and animals with the sun which develop out of myths and ceremonial usages. A good story may incorporate knowledge, or it may be an acceptable substitute for knowledge. Ethnologists working among primitive peoples find that myths furnish important leads in many fields of research even though they contradict each other. Some myths try to explain how the universe was created, who was responsible as creator, how modifications making things better or worse were introduced. Myths may even explain the nature of the sun and other heavenly bodies: for instance the sun may be a person or an object that is carried. The sun may be either male or female, and the moon as well. These two orbs may be brother and sister, husband and wife, or they may be friends or enemies in various mythical explanations and they may have adventures taking them far from astronomical orbits.

Mythology once was explained as an esoteric art in which demigods act out subtle allegories of nature. Some justification for this belief is found in Persian, Greek, Roman, and Teutonic tales which survive in polished literary forms; also there are really primitive tales in which aspects of nature are personified. For several generations the fashion held to psychoanalyze nearly all myths into sun myths, explaining broadcast features not by transmission in social intercourse but by reinventions with the psychic unity of man as a controlling factor.

Illustrating how far this kind of explanation formerly was carried, Brinton even explained the Toltecs, a civilized nation who ruled in Mexico and Central America before the Aztecs, as part and parcel of a sun myth. He admitted that the inhabitants of a certain Mexican town might have been called Toltecs but denied them any supremacy either in power or the arts. Their empire, he insisted, was a baseless fable, the product of a tendency to merge ancestors into divinities and of a confusion between Tollan, City of the Toltecs,

and Tonallan, City of the Sun. He concluded that "the ever-living light-and-darkness myth of the gods Quetzalcoatl and Tezcatlipoca" had glorified legend.

But Brinton's etymology was erroneous. Moreover, there actually was a supremacy in Toltec arts while Nacxitl Quetzalcoatl was an historical ruler although confused with a Maya divinity whose worship he introduced into Mexico. Perhaps Tezcatlipoca also was a real politician whose scheming was disastrous. Shortly after 1900, students began to suspect that solar symbolism has been laid on too thickly. Ehrenreich, comparing American and Old World myths, accepted some proofs of diffusion which broke the pattern of psychic unity. Lowie in 1908 took solar and lunar myths in which heros had been tested, and tested the myths themselves. He concluded that "solar and lunar heros are human beings named after or somehow identified with Sun and Moon"—the pendulum had swung to an opposite extreme!

But primitive myths help to define the kind of ideas which early man held about nature. We cannot even give in summary the vast array of ancient and modern tales in which the sun figures. Of course, the possession of a sun myth does not prove the existence of sun worship among a given people, although when sun worship does exist it is generally reflected in vivid tales. Let us take the Navajo: they live in proximity to the Pueblo Indians among whom well-developed sun cults are practiced. A digest of their solar mythology is typical of knowledge and imagery found in an early stage of sun worship.

The Navajo have a powerful god called Day-bearer who carries the sun, which is described as a disk made of clear stone with inlaid turquoise around the edge and a fringe of rays consisting of red rain, lightnings, and many kinds of snakes. This Day-bearer is a somewhat impersonal god who travels a sunbeam or rainbow path across the sky and who has an eastern and a western wife. He receives little direct worship, but his western wife, Woman-who-rejuvenates-herself, is the most powerful of the Navajo deities, and their son is also most conspicuous. Washington Matthews translates the son's name as Slayer-of-the-alien-gods. Here is a verse from a Navajo song:

> The Slayer of the Alien Gods, that now I am,
> The Bearer of the Sun, arises with me
> Journeys with me, goes down with me
> Abides with me, but sees me not.

The sun does not appear in the cosmic myth of the Navajo until the Twelfth or Uppermost World has been reached in the ascent of rudimentary human creatures. "When First Man had made all

things for the Earth and sky and given them stability, he selected the Gourd Children * * * to carry the Sun and Moon. These he placed on their left shoulders, leaving their right hand free to enable them to eat when traveling. Thirty-two trails were assigned to the Sun for his daily travels. To compensate themselves both the Sun and the Moon (carriers) stipulated one human life for every journey." This sounds like human sacrifice, but the actual ritual of sun worship may be hinted at in a song of the Mountain Chant:

Where the Sun rises
The Holy Young Man
The Great plumed arrow
Has swallowed
And withdrawn it.
The Sun
Is satisfied.

Where the Sun sets
The Holy Young Woman
The Cliff rose arrow
Has swallowed
And withdrawn it.
The Moon
Is satisfied.

A sober analysis of Navajo ideas of the sun contained in their mythology and reinforced by the fine body of sand paintings and song sequences used in their ceremonies shows little in common with the ideas of other Athabascan tribes living in the north but much in common with ideas found among their Pueblo Indian neighbors. These in turn have elements in common with artistic conventions prevailing in Mexico and Central America before the Spanish conquest, in each case the inspiration resulting in an incomplete transfer. The Mexican nations accepted little of the science of the Mayas, the Pueblo Indian communities little of the astrology of the Mexicans, the Navajo bands little of the agricultural aim developed in the Pueblo community—in each case there had been a step-down transformation. Yet enough had been implanted to assure a new growth under color of a new collective personality. This can be illustrated objectively by the way in which representations of suns succeed each other in Maya, Toltec, Aztec, Pueblo, and finally Navajo art.

THE BEGINNINGS OF ASTRONOMY

The reader will understand that the nature of the available evidence on sun worship prevents a steady advance in the argument. It is necessary to move backward to archeological beginnings, forward to ethnological stages that seem to present a recapitulation of developmental stages, and then test the whole in the light of history.

Anthropology combines arguments from many sources to reveal the truth concerning man—a medley from all sciences and all arts brought to bear on the animal with a flowering psyche. Heliotropisms, or unintelligent responses to stimuli of the light and heat of the sun, relieve many lower forms of life from the necessity of thinking. Man alone in the animal kingdom makes rational and ceremonial

responses which rise above occult seasonal urges in most of his dealings with nature.

True solar cults doubtless await the domestication of food plants and the establishment of fixed abodes, but primitive hunting tribes, as one may still learn by field work in ethnology, normally make offerings and vows to the sun, also acquiring a practical knowledge of solar and other celestial movements by continuous observation. There are some areas in which primitive man seems strangely inert to solar appreciations, aboriginal California being a good example. But here where solar motives are inconspicuous in art and ceremony, we find calendars of moons in general use. And calendars with moons are relatively advanced.

But the Australian blacks are primitive enough. They have no months as we understand the term. Nor do the Indians who live along the Amazon have months, and as for numbers, some tribes lose all interest when these run above six. Yet both the Australians and the Amazonians construct many marvelous constellations, and both take note of the season when this or that star group makes its first appearance in the east before sunrise. Each constellation in order brings, they think, a food or an activity. These lowly human societies correlate the year of the stars with the year of the sun. Actually there is a 20-minute difference, amounting to 1 day in a lifetime, which they do not recognize.

The slightly erroneous belief that the sidereal year coincides with the tropical year also was held 6,000 years ago in western Asia. Ultimately, the testing of this concept produced the science of astronomy or at least tremendously enriched it. Ultimately attention to the sun and stars built up the power of kings and led to high forms of religion. For out of the star groups that lay along the path of the sun was formed the measured speedway of the zodiac where the planets raced. Although this zodiac with its 12 classical signs is familiar enough to the modern man of the city, he is less likely to associate it with studious astronomy than with her flighty sister astrology.

At first it was not the full, formal zodiac. The constellation of the Bull marked the vernal equinox and those of the Lion and the Scorpion the summer solstice and the autumnal equinox, respectively, all determinable stations of the tropical year.[2] Doubtless the first appearances of other constellations were signals for dances honoring various animal gods. Elsewhere in Asia, Europe, and Africa the

[2] The swinging points of sunrise and sunset with the solstices at the two extremes, and the equinox when sunrise and sunset shadows form a straight east-west line, are universally recognized and the solstices commonly observed in ceremonies that pay respect to the sun.

stars may have been grouped quite differently, but seemingly the same principle of association obtained, by which times of the year could be plotted in the sky. We know that many constellations of the Egyptians were sufficiently distinct from those of the Babylonians and the Greeks. Yet the fact that dwellers on the Nile connected the bright star Sirius, which they called Sothis, with the flood stage of that great river shows clearly enough that they, too, naively considered the sidereal and tropical years to be one and the same. Also, I think, it is not impossible that Hathor and Sekhmet, anthropomorphic cow and lioness wearing the sun disk on their heads, may once have had some connection with the vernal equinox and the summer solstice paralleling the Bull and Lion signs of Mesopotamia. Sekhmet was goddess of devouring desert heat, and when would that be worse than under the high sun? Wainwright gives evidence to the effect that Heliopolis was originally a center of solar worship identified with a Pillar of the Bull. The pillar in solar symbolism refers, I believe, to a column used to test and measure shadows. At the equinoxes morning and evening shadows make a straight line, at the solstices noontime shadows are shortest or longest of any during the year.

The recognition of the sidereal year as a practical concomitant of the tropical year was common before the effort to balance the movements of moon and sun in compromising luni-solar calendars. The star cluster Hyades was so named by the Greeks because it appeared at the rainy season. They also paid their respects to the Pleiades because these stars rose with the sun at the planting season and set with the sun at harvest time in the northern hemisphere, whereas in south Africa where the seasons are reversed the Pleiades are known as the Ice Maidens. Historically early and culturally primitive evidence supports the conclusion that the sun's movements were correlated, first of all, with constellations taking the forms of animal gods. This, in itself, is not enough to constitute sun worship.

THE SUN AS DYNASTIC FATHER

The earliest high civilizations of the world were theocratic; in other words the kings operated as the spokesmen of divinity. A shamanistic origin for such great power is indicated, for the shaman gains prestige through magic, and magic has a stronger hold on the imagination of men than mere physical prowess or the advantages of wealth or the respect due a patriarch.

Anthropomorphic gods and divine kings are pretty closely linked at different stages in their historical development. During the nomadic hunting, fishing, and root-gathering stage the gods, if you will, are generally animals and birds—natural creatures who can

help man because they are his double in spiritual and intellectual qualities while also possessing their own personal skills which they willingly teach to man if properly approached by a shaman. In this way the pelican becomes a fishing god and the lion a hunting god. It is the shaman who gets in touch with these animal deities and who manipulates the transference to them of the spirits of the dead. It is the shaman who by disguises and medicines can convert himself into the animal invoked.

When man first turned from hunting to farming, he found himself more and more exposed to those vagaries of climate that we call weather. Too much or too little sunshine or rain during the growing season spelled failure for his crops; too early or too late planting brought other misfortunes. The result was that the old masters of all magic, the shamans who had laid ghosts, and who overcame disease and looked after the game supply, were now given new jobs in crop protection. It seems that the help of the dead was asked in the matter of germinating seeds. It seems that female figurines became fetishes of fertility coercive on Mother Earth. It seems that the movements of the sun and stars were studied and astronomical facts were discovered which greatly enhanced the prestige of successful shamans. It seems that animal gods became specialized as totems, as district protectors, as patrons of crafts, as weather animals, as personalities for stars and planets.

Also an assured food supply let populations increase and gave time for arts and ceremonies. Pottery, replacing basketry, gave a new vehicle for design, magical or decorative as the case may be. According to a theory now coming into vogue, the agricultural civilizations of the Fertile Crescent did not really begin on the flood plains of the Euphrates or the Nile but on the hills of Elam, Anatolia, Palestine, and Libya. Here there had been, first of all, a gathering of wild crops. Perhaps some plants were tamed in situ in natural gardens, others by hand planting in irrigated fields. Then the lowlands were occupied, but only after considerable progress had been made in the upbuilding of concepts of divinity on the one hand and sacred leadership on the other. The part which astronomy played was doubtless great as is indeed hinted in predynastic pottery designs found in the lowest Chalcolithic[3] levels in western Asia. Sacred animals, trees, stars, suns, and sometimes patterns that may involve a concept of the world or the universe are found here. Among comparable Egyptian remains sacred animals are prevalent;

[3] The Chalcolithic is the cultural equivalent of the Neolithic of northern and western Europe but may fall considerably earlier on the time scale. Native copper, which does not mean a metal age because there is no smelting, sometimes leads to the designation Eneolithic. Actually the word Chalcolithic is applied to early remains with accomplished flint chipping distributed from the Mediterranean to the Indus.

there are boats, trees, and standards which some explain as totemic crests. Few predynastic Egyptian references to the sun or to the stars are found; nevertheless, the earliest godheads of dynastic times are connected with the sky. In both Mesopotamia and Egypt half-animal, half-human gods walk through the gloaming as civilization dawns.

In arranging Mesopotamian seals in chronological order, Legrain really gives data on the evolution of gods. The first predynastic seals are flat stones with the backs carved to represent the lion, the bull, and the eagle, the fronts having geometric patterns, simple scenes with mountains, animals, hunters, huts, nets, suns, stars, crescents, double-headed eagles, and bull-men. In the next group, early Sumerian and shortly before dynastic times, which began about 3000 B. C., there are designs which portray the prototypes of Gilgamesh and Eabani, commonly explained as solar heros who are humanized bison and bos and who fight wild animals. Later still comes Shamash the sun god, described as: "Shamash, the young hero of light, opening the gates of dawn, rising at morn over the Persian hills armed with his golden saw, the divine archer who pierces with his golden arrows the powers of darkness, the mists and the stormy cloud brooding over the mountain, who breaks the backs of his enemies and their clubs, pulls off their crowns and their beards, the triumphant warrior who passes at noon the tops of the stage towers, the great divider between day and night, the supreme judge from whom nothing is hidden."

SUN WORSHIP IN MESOPOTAMIA AND EGYPT

But when gods such as that are represented in human form, an essential process of change has been completed; for gods in kingly guise are a reciprocity for kings in godly guise. After the opening of the dynastic period the kings of Mesopotamian states were not only the representatives of gods but effectively they were themselves gods. The Sumerian word *patesi* which means "vice regent of a deity" continued to be used by Assyrian rulers. To be sure the record of identification of the king with the god is not as complete in Mesopotamia as in Egypt. Hammur-abi appears before the sun god and calls himself the sun god. On early sculptures the blazing sun star protects the king, and on later ones the winged disk of the sun, imported from Egypt, serves the same purpose. Sun worship is pictured on splendid monuments where the sun god seated on a throne has libations poured in his honor (see pl. 1).

One main difference between sun worship in Mesopotamia and Egypt is that in Mesopotamia Shamash and other gods with solar attributes are in human form, whereas in Egypt we have original ani-

mal deities, Horus the Hawk, Hathor the Cow, Sekhmet the Lioness, etc., who at best are only semihuman and who wear the solar disk. Another difference is that the nations of Mesopotamia developed a definite astronomical science, recording the movements of Venus and other planets, learning to predict eclipses, etc.—achievements that depended on their having a zodiac. Their ritualistic astronomy became astrology as the planets were plotted in the heavens to determine fate. The Egyptians developed a rigid priestly year of exactly 365 days which they attempted in one formula to correlate both with the rising of Sirius and the flooding of the Nile. These natural events during one 1,460-year cycle of Sathis grow 12 days apart. Yet sun worship was more purely and completely a state religion in Thebes and Memphis than it was in Babylon or Nineveh.

As a relic of dynastic beginnings in Egypt the Serpent King's ivory comb nicely supplements his fine stela. On the comb Horus, the Falcon, rides above the title in a boat which one is tempted to identify as the boat of the sun in later Egyptian art. If this identification is made, the masonry ship of the sun shrine complex has a fuller meaning and Horus commences his career, so to speak, as a sun god instead of a sky god. Also we find the very early Scorpion King with hoe in hand inaugurating, perhaps, an agricultural season as the master farmer. Irrigation called for regimentation of labor and must have been a factor in the upbuilding of kingly power. Titles indicate a priority of Horus and a somewhat later rise of Re as sun god. The first Re kings belong to the Second Dynasty beginning with Neb-re. The great Zoser of the Third dynasty called himself Re-nub, the Sun of Gold. Some writers claim that there was a violent turn-over in the priesthood as each early Re king was followed by others who did not carry this specific sun title.

The Egyptian pyramids are associated definitely enough with sun worship, as are also the obelisks. This fact comes out in the inscriptions, but in addition the orientation at Giza is almost perfect. The Great Pyramid has a deviation of 0°3′43″, averaging the four sides, from the cardinal points. Although the epithet "pyramidiots" has been proposed for astronomical theorists, the orientation of this group of pyramids is too close to be dismissed as accidental; the associated temples face true east.[4] The sun shrine of Ne-user-re is placed with pyramids, but really it is a ceremonial enclosure with a massive obelisk also showing orientation. The architectural sun ship is outside the enclosure. The inscription, associated with stars and standards, deals with ceremonies planned to renew the forces of the king.

[4] In Archeology and Astronomy, Dinsmoor reexamines orientation theories and data. He shows, for instance, that the axis of the Parthenon was derived from the sun on the natal day of Athena.

There is every evidence that religion in Egypt was a matter of priestly manipulation. It is true that the pharaoh was considered divine from first to last, but it is not true that he was free. Whether or not he was sacrificed after the manner of a dying god is not yet clear. But the modern African examples of sacrificed kings certainly cannot be considered a survival from early Egyptian times—the one thing which does not distinguish Negro culture is social continuities.

The really tremendous innovations of Amenophis IV, better known as Ikhenaton, resulted in a sun god who was the only god recognized by the state. It was, I suppose, the world's first taste of monotheism. The symbolism of the sun's rays ending in human hands was an invention of Ikhenaton. This king according to a recent commentator was "a revolutionary leader who took the temporal and religious power into his hands, overthrew an age-old, absurdly elaborate religion and founded a monotheistic cult of the Sun, as the great central force of the human world."

On a tomb at Amarna, the capital of this king, are written these verses:

> Bright thou dawnest, my Father,
> Thou life-teeming Sun,
> Thou art the only one,
> Yet thou art all life,
> Thou art my life!

The beautiful Hymn to Aton, written, it seems, by Ikhenaton himself, has often been quoted. I give three passages:

> The dawning is beautiful on the horizon of heaven, O living Aton, Beginning of Life! When thou risest in the eastern horizon of heaven, thou fillest every land with thy beauty; for thou art beautiful, great, glittering high over the earth; thy rays they encompass the lands, even all thou hast made * * *
>
> O thou sole god, whose power no other possesseth, thou didst create the earth according to thy desire while thou wast alone; men, all cattle large and small, all that are upon the earth, that go about upon their feet; all that are on high, that fly with their wings * * *
>
> Thou makest the beauty of form through thyself alone, cities, towns, and settlements on highway or river. All eyes see thee before them, for thou art Aton of the day over the earth. Thou art in my heart, there is no other that knoweth thee save thy son Ikhnaton. * * *

The appeal of sun worship was in the example of resurrection which the sun furnished. This is brought out in the wonderful sarcophagus of Taho, son of Peteheka, a work of the Saite revival. Of the purpose of the rich designs Boreux writes: "One gathers that in order to assert that the deceased is as indestructible as the Sun or, indeed, perhaps to make him so, every carving represents or suggests the Sun's daily birth." One picture shows the sun disk being

passed from the evening bark to the morning bark by two female divinities—perhaps at the moment of midnight on the underworld river. Another picture shows the sun's disk raining a golden blessing on the soul of Taho which takes the form of a bird.

From the cultural foci of Mesopotamia and Egypt influences went north and east.[5] Evidences of solar worship in northern Europe have been left in the magnificent memorial of Stonehenge, in the sun chariot of Trundholm with its gilded disk and its horse mounted over six wheels like a Christmas toy, in the clay cult-wagon of Duplaj in Yugoslavia drawn by three ducks with a roughly fashioned sun god standing over his symbol as he drives. Lesser evidences of sun worship during the Bronze and Iron Ages are seen in Swedish rock carvings with suns held aloft in boats, not to mention the numerous amulets that represent the sun as a wheel, or rising above a boat, etc. The designs become richer as we draw near Greece and come under Mycenaean and Cycladic art; now there are suns and swastikas, suns and ducks, suns and funeral processions.

THE SUN AS A RADIANT PERSONALITY

We come at last to a sun god who truly is a radiant personality—a god in human form with a ring of light about his head. The Egyptians, as we have seen, balanced a sun disk on the heads of various part-animal, part-human sun gods. Then the inspired Ikhenaton invented an elevated sun disk with numerous pendant rays ending in small human hands. At this point the humanization of the sun god stopped in Egypt until the late vogue of Amun. In Mesopotamia, as we have also seen, the gods enter the dynastic period essentially in human guise. Shamash, the sun god, may have the flaming orb above or before him or he may be pictured with rays of light streaming upward from his shoulders. In late Assyrian representations he is sometimes shown with a halo around the upper part of his body, an especially clean example dating from the reign of Asurbanipal (668–626 B. C.).

But I think, for all this, we should credit the Greeks with essential refinements that produced the halo as a living convention in religious art. References to Helios go back to Homer, but on a black-figured Grecian vase (circa 600 B. C.) the charioteer is identified as Helios by an overhead disk. Next he is pictured in all splendor on a famous red-figured vase of the British Museum, with spiked rays of light shooting out from his head. We may imagine that the Helios of the Parthenon pediment was of this general style. The island of Rhodes was sacred to Helios and its coins before 304 B. C. show the god with streaming locks like Apollo. After that date he wears his spiked halo.

[5] The writer wishes to acknowledge important help from John D. Cooney and Mrs. Elizabeth Riefstahl, of the Brooklyn Museum staff, in the handling of classical data.

The Colossus of Rhodes, a harbor statue, named as one of the seven wonders of the ancient world, must have represented Helios, and we may speak of New York's Liberty Enlightening the World as the sun god's sister in an artistic sense. Helios in his chariot was carried as an artistic motive to Dura-Europos, to India, to Turkestan, even to China. Also it survives in various adaptations down to modern times. This is no denial of the fact that miniature sun chariots, employed as cult objects during the Bronze and Iron Ages, may have been responsible originally for the Helios convention.

Can any earlier god be called radiant in the same sense as Helios? Did the light from the shoulders of Shamash develop into a true halo? Apparently not. The leading possibility of a source anterior to the date when the artistic characteristics of Helios became fixed among the Greeks would naturally be sought in representations of the Iranian god Ahura-mazda under Cyrus and his successors. The sculptures dealing with Darius exhibit the winged sun disk combined with a long-robed priestly figure and are a carry-on of the Assyrian convention derived originally from Egypt. Royal memorials and tombs on the Persian plateau reflect the contemporary usage in the lowlands in picturing the sun, with simple forms of the winged sun disk on the tombs of early Medic kings.

Herzfeld in The Throne of Khosro brings together many curious references concerning Helios. It seems that the first Persian sun god with rays about his head was Mithra, mostly a derivative of Ahura-mazda, but touched by Greek artistry and dating from the end of the Greek dynasty of the Seleucidae. Even if Mithra, as some claim, is ancient in Cappadocia the sun god pictured with Ardashir II (d. A. D. 383) is in the Helios tradition. The Sassanian kings restored the Zoroastrian religion and the winged sun disk adorns the crown of Khosro II (d. A. D. 628). Mithraism was an active religion, and the slaying of the heavenly bull by Mithra is a vernal equinox ceremony inspiring monuments in Syria and several parts of Europe. The Mithraic festival of the winter solstice gives rise to our Christmas.

When Alexander the Great became an Egyptian pharaoh, he automatically was made a god after death. Apotheosis was regular among his Ptolomaic successors and was also adopted by the Romans. Normally, these deified beings reached heaven in the chariot of Helios. This vehicle is pictured on the Altar of Malachabel at Palmyra. Another representation on a tablet of ivory in the British Museum is called the Apotheosis of Romulus and may refer to a certain M. Aurelius Romulus Caesar who died in A. D. 308. The ghost is swept upward across the zodiac in the chariot of Helios.

Another adaptation of the chariot of the sun god is an early mode of depicting Christ's Ascension. In the Coptic church at Bawît in upper Egypt, belonging to the Monastery of St. Apollonaris, there

are two paintings of the Ascension. In both cases we see Christ against a great auriole like the disk of the sun. The wheels of the chariot are diminished in size but still visible, and Eôos, Aithiops, Brontè, and Steropè, the four steeds of Helios, are in process of being transformed into the animals of the evangelists (pl. 4, fig. 1).

During the Middle Ages the chariot of Helios in modified fashion is pictured on an Alexandrine textile of the seventh century. In the Saxon World Chronicle, Khosro, the Sassanian king, is shown on his throne under the name of Cosdras. The design represents this ruler on a divine seat between the sun and moon and surrounded by the stars—a final echo of the Helios tradition.

Chinese religion centers around the worship of heaven rather than of the sun. In Chinese art the sun disk generally encloses a three-legged crow to which there are ancient references and of which there is an example in early Han sculpture. Sun disks containing ravens are frequent at Tun Huang, the site of the Thousand Buddhas, more particularly as emblems held in the hands of the Bodhisattva of Mercy. On a silk coffin cover from Astaña an attractive painting of Fu-hsi and Nüwa, a legendary emperor and his wife, shows intertwined serpentine bodies surrounded by the sun, moon, and stars (pl. 4, fig. 2).

The Japanese religion called Shinto recognizes the sun goddess Amaterasu as the head of the pantheon. A mirror at the national shrine at Ise is sacred to this goddess, who is regarded as the ancestor of the Imperial family. Amaterasu is adored by pilgrims who climb Fujiyama to view the sunrise from its summit. The raven is the messenger of Amaterasu, and the cock announces her coming.

Elsewhere in the Old World there are sun gods and sun cults of minor standing. The Arabs cultivated astronomy as a science and astrology as a ritual and implanted the latter wherever they went.

SUN WORSHIP IN AMERICA

"The details of Sun-worship among the native races of America," says Tylor, "give an epitome of its development among mankind at large. Among the ruder tribes of the northern continent, the Sun is looked upon as one of the great deities, as representative of the greatest deity, or as that greatest deity himself." Much information has been collected since the above was written, but the conclusions are still valid.

Among some American Indian tribes the sun is treated with continuous respect and adoration without being the object of any highly dramatic ceremonies. The Pueblo Indians of New Mexico and Arizona greet the sun ceremoniously at dawn with thrown offerings of sacred meal and hold special rituals at the solstices. Then the sun reaches a sun house and rests for several days before reversing his

journey. These sun houses are points on the horizon which for each village mark the extreme northwesterly or southwesterly sunrise positions. Foot races in late autumn have the sympathetic purpose of relieving the travel-weary sun. The Summer People's Song of the San Juan Race Dance is concerned with this magic:

Old Man of the Sun!
Stand ready at dawn
On Cactus Ridge!
Old Man of the Moon!
Stand ready at dawn
On Cactus Ridge!
Stand ready at dawn,
Thence for San Juan!
Stand ready at dawn
For Eagle-Tail-Rain-Standing Road!

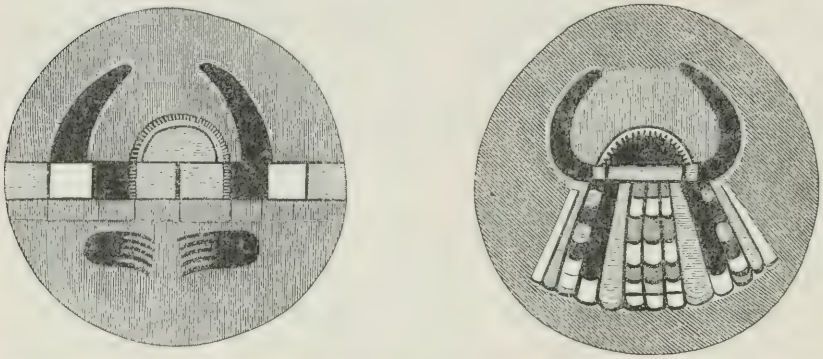


FIGURE 5.—Buffalo-hide shields of the Pueblo Indians, New Mexico. Left, decorated with band of galaxy, with sun in center, buffalo horns at side, bear's paws at bottom; right, the sun with buffalo horns wearing the sun's shirt, streamers of light over clouds.

In the dead of winter there is a New Fire Ceremony which has the purpose of recovering the sun's heat. The Sun Katchina Man, a masked personifier, is a splendid figure with a round, feather-fringed face. On Pueblo war shields the sun wears bison horns and a shirt that consists of streamers of light.

The Sun Dance of the Plains Indians was also a summer solstice ceremony with other purposes intervening. Originally the Plains Sun Dance regulated nature for man's benefit. "The dancers," says Dorsey, "collectively overcome an enemy, generally the Sun, and by their medicine compel the Thunderbird to release rain." Participants represent gods of four directions, and details of costume as well as painted decoration are not only symbolic but also coercive. The self-torture elements of the closing ceremony derives from an ancient American Indian belief that the sun is a helper of warriors.

The Natchez tribes on the lower Mississippi had intensified sun-worship, perhaps a survival of Mound Builder religion. Inheritance of the kingship was on the female side and there was compulsory out-marriage in the ranks of nobles. The Great Sun was succeeded by the male child of his sister and a commoner. The worship consisted in the maintenance of a never-dying fire, and the nobles were accompanied in death by their strangled mates and other victims.



FIGURE 6.—Maya representation of the Heavenly Canopy. The sun disk at upper left, moon at upper right, and sky god—a humanized jaguar—between. Below are signs of the planets and the faces of the sky god. Yaxchilan, fifth century.

The origin of high-plane sun worship in America should be ascribed to the Mayas, who developed astronomy to the highest perfection of any ancient people. They had a system of writing and a notation of numbers, the latter in place values, and their astronomical accuracy rested on a day count, in which celestial happenings were recorded. They had a zodiac and handled the sidereal and synodic revolutions of planets, the recurrence of eclipses, and true measures of the year. The Maya sun god was a jaguar who became more and more human-

ized. He ruled the phenomena of the unclouded sky and was opposed by a serpent god of the clouded sky who also manipulated some of the planets as covert enemies of the sun, especially Venus.

The social situation during the First Empire of the Mayas which ended about A. D. 630 was purely theocratic, with rulers often wearing the masks of gods, especially the jaguar mask of the sun god. There was a collapse and a rebuilding, but in later times less religious intensity is manifest.

It appears that the jaguar sun god became established among the nations of Mexico and Central America and that certain controlling ideas probably passed south along the Andes to Peru and beyond.

The evidence of the transfer of sun worship to the Toltecs, the Zapotecs, Mixtecs, Totonacs, Aztecs, etc., is clear and detailed. The sun god becomes more and more a protector of those warrior societies

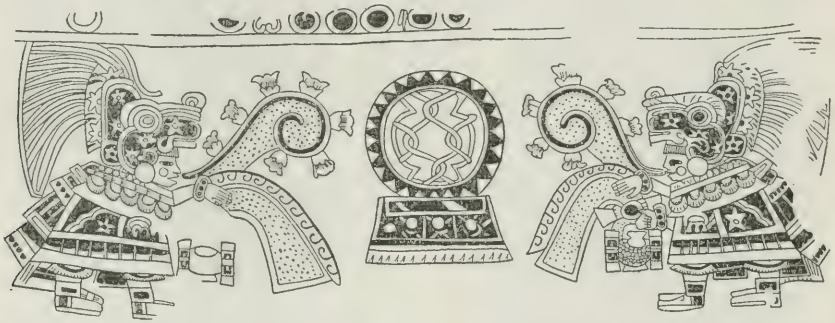


FIGURE 7.—Sun worship of the Toltecs. Two priests pray for flowers and scatter water and seed. The sun disk raised on an alter has pointed rays such as are characteristic of later Mexican sun symbols. A fresco painting at Teotihuacan of about A. D. 1200. At Chichen Itza contemporary representations show transition to the sun disk with serpent rays.

called the Jaguars and the Eagles. Human sacrifice was introduced, it seems, by the Toltecs, being connected especially with the rites of apotheosis for eminent war chiefs, which also were rites of rejuvenation and fertilization benefiting agriculture.

The Aztecs had a sun god proper called Tonatiuh and several other divinities with solar aspects. This sun god was not the most powerful deity of their pantheon, yet several of their grestest monuments present the conventionalized disk of the sun. The Calendar Stone is one of these, and another the great Stone of Tizoc recording early victories of Aztec arms. The face of the sun in Aztec ideographic writing carries the general meaning of god rather than the specific meaning of sun.

The southern movement is more dramatic, being documented in the art of Panama, Colombia, Ecuador, Peru, Bolivia, and Argentina. A striking similarity in subject matter exists between the Jaguar Stairway at Copan and numerous South American monuments. The former shows a sun god's head engaged between Venus symbols, and at either side are rampant jaguars. The date is a round number in the Maya day count corresponding to March 27, A. D. 511, Gregorian calendar, which fell at an inferior conjunction of Venus and the sun in the Maya zodiacal asterism of the Jaguar. Jaguars flanking the sun god, who is himself a jaguar, occur in Peruvian art on the Tiahuanaco level in combination with sun disks having serpent rays, the latter also a Maya convention (see pls. 5, 6, and figs. 6–9).



FIGURE 8.—Bronze plaques of the Calchaqui culture, area of northwestern Argentina. Two jaguars supporting the sun god. The motive shown here may take its origin at Copan, Honduras, where the magnificent Jaguar Stairway shows two large rampant jaguars on either side of the stairway, and in the center above, the sun god between two Venus symbols. The monument is part of a dated group. Jaguars guarding the jaguar sun god are common in Peru on pottery, stone lintels, and monolithic statues, where sun disks with serpent and jaguar rays also abound.

Sun worship was the state religion of the Incas of Peru at the time of the Spanish conquest. Part of the great Coricancha or Sun Temple at Cuzco survives in the Monastery of Santo Domingo. A diagram of the high altar is probably preserved in a drawing of Santa Cruz Pachacuti-yamqui Salcamaja with some explanations of its astronomical details. In this temple were displayed all the dead Incas in jewel-covered mummy bundles either genuine or simulated, together with a golden image of the sun. Of course the Spaniards lost no time in despoiling this cultural center of its negotiable contents. A certain

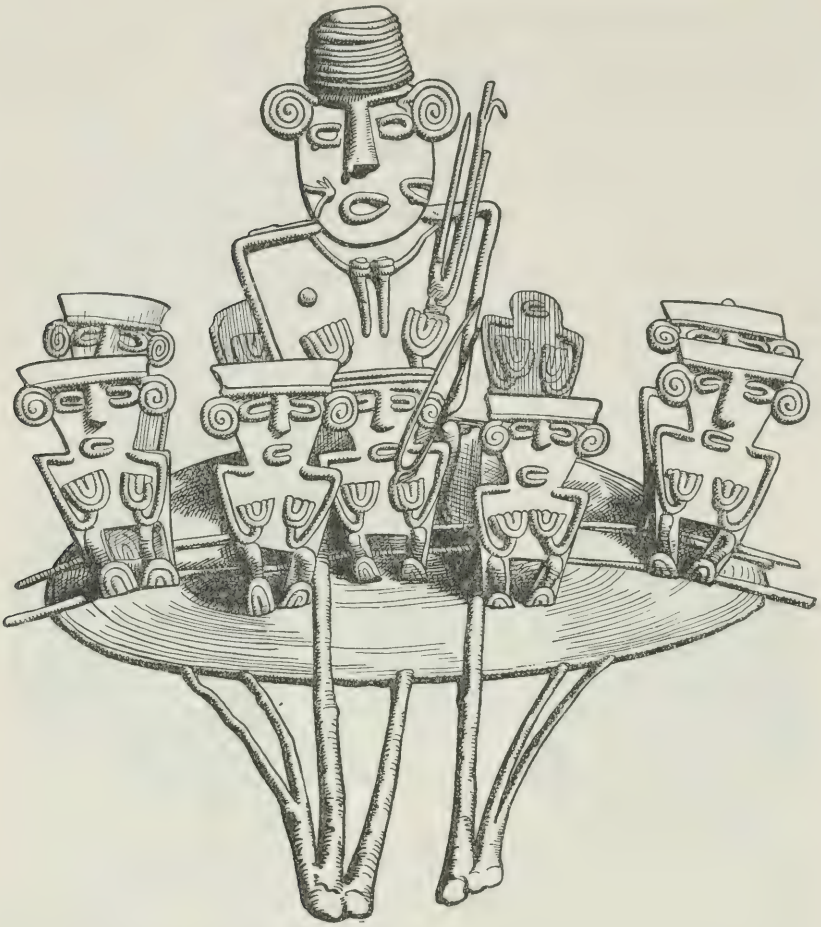


FIGURE 9.—The sun god amid his worshipers. Chibchan gold object believed to refer to El Dorado, the gilded sacrifice to the sun at Lake Guatavita, Colombia, but similar to representations at Recuay, Peru (see pl. 6, fig. 1), may relate to a ceremony in a tower.

Mancio Sierra de Leguizamo gambled away his share of the loot, "a figure of the Sun, made of gold which the Incas had placed in the house of the Sun in Cuzco."

Rituals were controlled by Incas of high rank, for this Peruvian sun worship was family, or rather dynastic worship. Human sacrifice has been denied and affirmed for the sun cult of the Incas. At any rate there were the convents of the Chosen Women, sometimes called Virgins of the Sun, who wove fine textiles. It seems they served only for a few years and finally were allowed to marry.

The lesson that the Mayas learned in studying the sun and stars in Yucatan was the lesson the Sumerians learned on the Euphrates: if

there is order in the universe there also should be order in the destiny of man. All this is said in Viracocha's hymn:

> The Sun, the Moon
> The Day, the Night
> Summer, Winter
> Not vainly in proper order
> Do they march to the destined place
> To the end!
> They arrive wherever Thy royal staff
> Thou bearest.

My conclusions are:

1. Practical observations involving the sun and stars for direction, time of day, time of year, etc., precede sun worship but should not be called sun worship.

2. On the earliest levels of agriculture shamans developed a religious interest in the sun as a factor in crop protection.

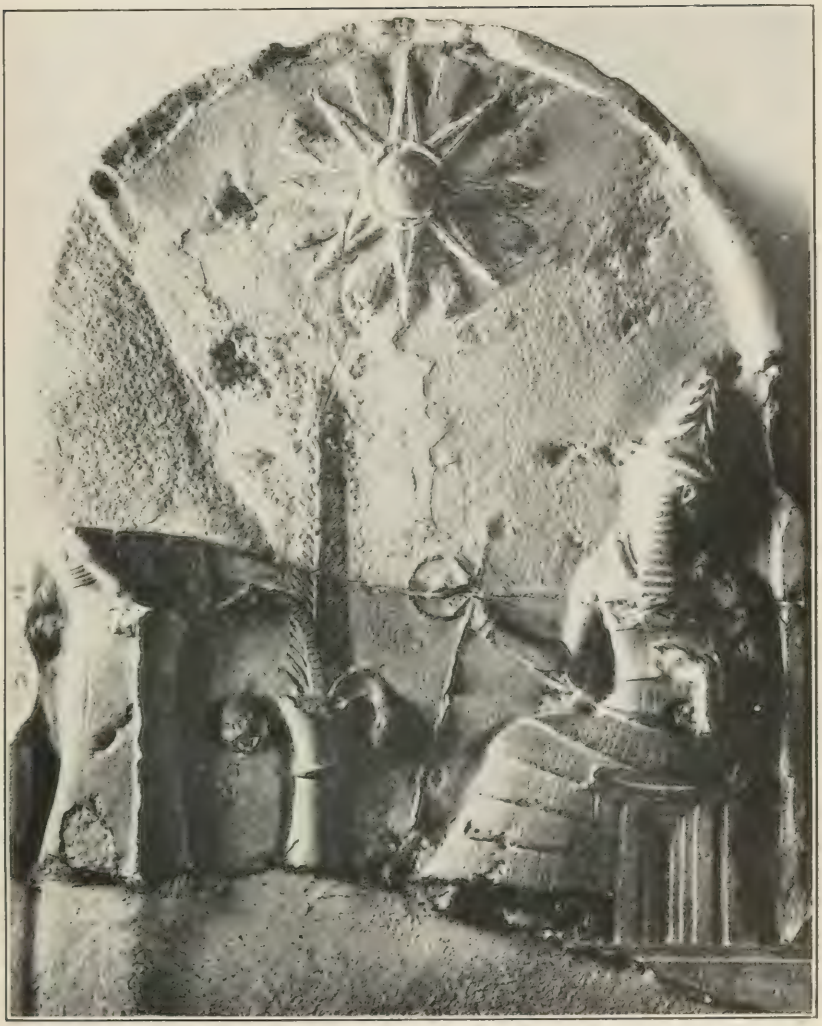
3. Nonagricultural tribes were infected from the higher centers of culture with certain solar concepts which they developed in their own ways.

4. Shamans developed into divine kings, and by a parallel process animal gods developed into anthropomorphic gods.

5. Sun worship as a dynastic cult had various independent origins.

6. Sun worship contributed greatly (a) to monotheism; (b) to godhead as a mechanical abstraction; (c) to godhead as an ethical abstraction.

7. Increased knowledge of the sun lessens its relative importance in the greater universe and drives abstractions farther back without reducing them in grandeur.

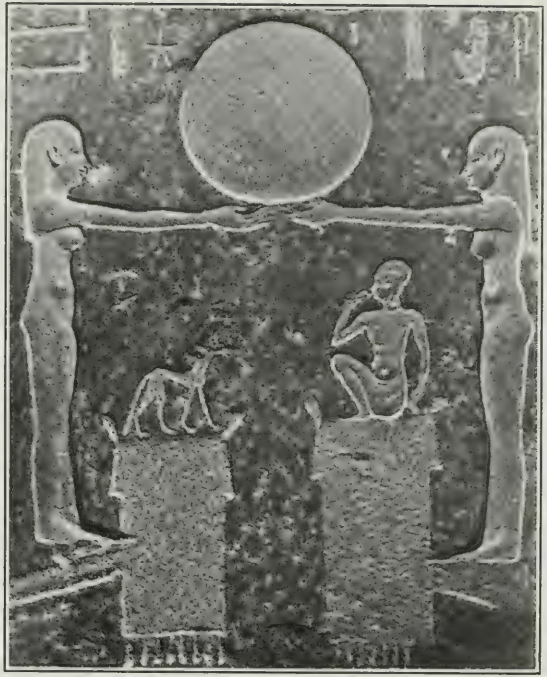


UPPER PART OF NEO-SUMERIAN STELA, TWENTY-THIRD CENTURY B. C., SHOWING SHAMASH, THE SUN GOD, SURMOUNTED BY THE SUN.

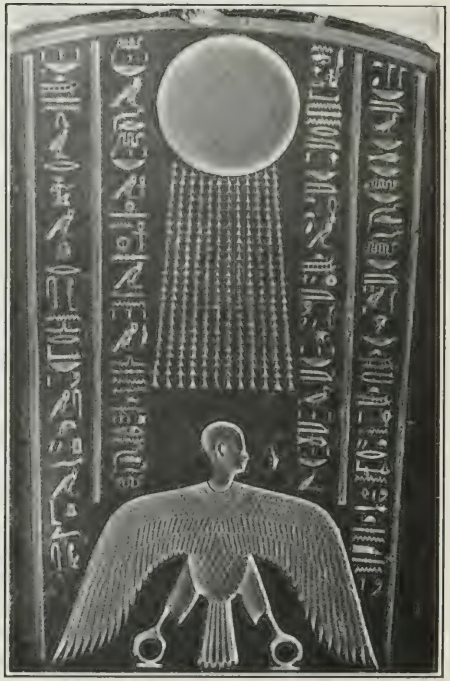
He is seated on a throne and a worshipper offers a libation before him. (Encyclopédie Photographique de l'Art, Paris, vol. 1, p. 247.)



1.

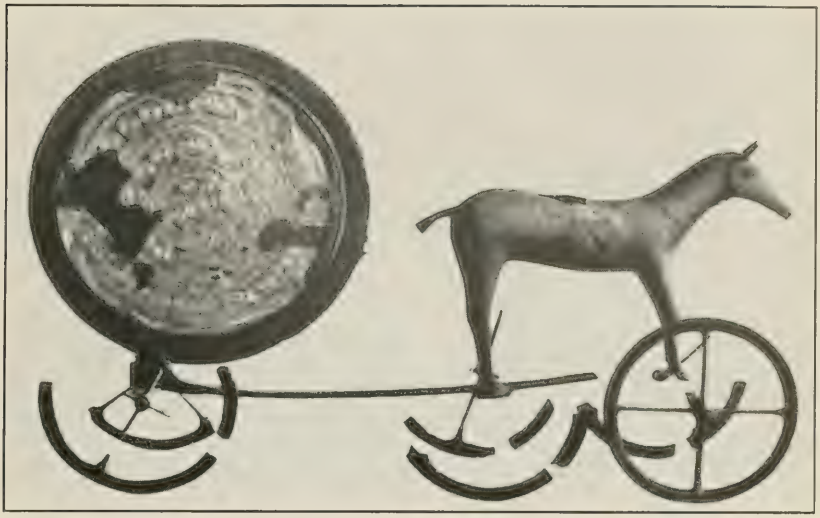


2.



3.

1. Lioness with sun disk, the Egyptian Sekhmet, the devouring sun of the desert heat, possibly the equivalent of the Mesopotamian asterism of the Lion, through which the sun passed at the summer solstice. 2. The course of the sun in the Duat. The sun is being passed from the boat of evening to the boat of morning. Sarcophagus of Taho, son of Peteheka. Le Musé du Louvre. (Encyclopédie Photographique de l'Art, Paris, vol. 1, p. 145.) 3. "The solar disk pours its rays down on the soul of the departed." Sarcophagus of Taho, son of Peteheka. Le Musé du Louvre. (Encyclopédie Photographique de l'Art, Paris, vol. 1, p. 153.)



1. THE SUN CHARIOT OF TRTNDHOLM, DENMARK, DATED RATHER EARLY IN THE NORTHERN BRONZE AGE.

The sun disk has remains of gilding and shows technical influence from the Mycenaean culture of Greece.

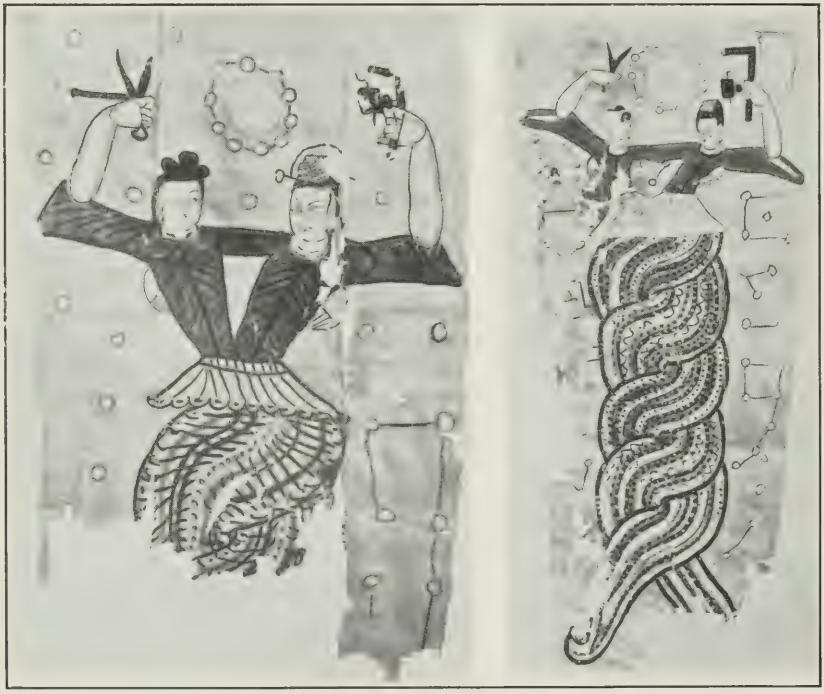


2. HELIOS, GREEK SUN GOD, IN HIS CHARIOT.

The other figures are alegorical. About 500 B. C. Red-figured vase in British Museum.



1. THE ASCENSION, MONASTERY OF ST. APOLLONARIS, BAWÎT, EGYPT.
In the oriental manner the Ascension follows the chariot of Helios tradition, as developed in Greek art.



2. A LEGENDARY EMPEROR OF CHINA AND HIS QUEEN, PICTURED AMONG THE STARS WITH THE SUN OVERHEAD.
They are Fu-hsi and Nüwa, the founders of Chinese polity. Painted silk cloth Astaña.



1. POTTERY VESSEL, RECUAY, PERU, SHOWING SUN GOD WITH JAGUAR PROTECTORS.

The decoration is by negative painting with wax, a process distributed from Mexico to Peru.



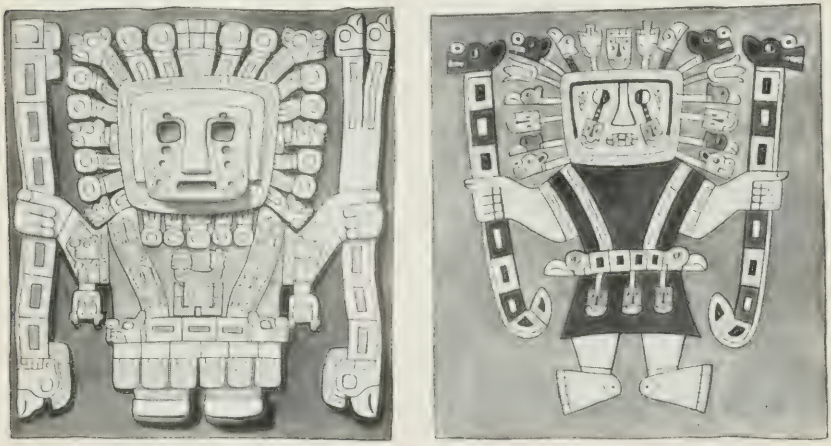
2. THE COURT OF THE JAGUARS AT COPAN, HONDURAS.

In the center of the stairway is seen the sun god with Venus symbols on each side of his face; at the sides of the stairway are rampant jaguars. The event was an inferior conjunction of Venus and the sun in the constellation of the Jaguar, March 27, A. D. 511, Gregorian calendar.



1. THE SUN GOD AMONG HIS WORSHIPPERS.

A Recuay pot from Peru.



2. THE SUN GOD IN THE EARLY PERUVIAN ART OF TIAHUANACO.

Left, the central figure of the sun god on the Gateway of the Sun, at Tiahuanaco, Bolivia; right, the sun god with jaguar-headed serpents, eagles, flowers, etc., as rays. The Tiahuanaco culture antedates that of the Inca.

THE USE OF SOAPSTONE BY THE INDIANS OF THE EASTERN UNITED STATES

By David I. Bushnell, Jr.

[With 10 plates]

INTRODUCTION

Steatite, generally called soapstone, is a variety of talc usually of a gray, grayish green, or brownish color. It varies in hardness according to its purity and composition and occurs in many localities from Georgia and Alabama in the south to the New England States, thence northward to the Arctic coast, and in Newfoundland. The composition and physical properties of soapstone vary greatly:[1]

Soapstone, properly speaking, is a massive rock, the chief mineral component of which is talc, usually present in sufficient quantity to give the rock a soapy feel. The term "soapstone" is sometimes incorrectly applied to massive talc. The composition of soapstone is exceedingly variable and its talc content may be as low as 50 percent. In fact, many soft, easily cut rocks in which chlorite predominates over talc are loosely called soapstone. Ordinarily, a soapstone of good quality contains, in addition to talc, varying amounts of chlorite, tremolite, pyroxene, magnetite, quartz, calcite and dolomite. Melting point, 1,350° to 1,400° C.

Soapstone was exposed on the surface in innumerable localities, and being so widely distributed and so easily obtained, was utilized by the Indians wherever found. In some instances pieces were removed from small, exposed masses; but in many localities, where the soapstone was of a proper quality and was well suited to the wants and requirements of the people, the work of quarrying continued over a long period and as a result a quarry workshop covering hundreds of square feet was developed. Sites have been discovered where quantities of broken, partly finished vessels were intermingled with pieces of unworked stone which had been removed from the quarries. Finished vessels are not encountered at the quarry workshops, but fragments of them are frequently recovered from ancient village sites, often far distant from the probable source of the material.

The age of the soapstone vessels, or rather the period to which they belonged, has not been definitely determined. This, and other

[1] Ladoo, Raymond B., Non-Metallic Minerals. New York, 1925.

questions presented by the occurrence of the stone and its use by the native tribes, will be briefly discussed in the present article.

All specimens illustrated, with the exception of several from Virginia, are in the collections of the United States National Museum, Washington, D. C.

AGE OF THE QUARRIES

In connection with the wide distribution of steatite and the great number of places where it was obtained by the Indians, two questions are presented: the age of the quarries, large and small; and the identity of the tribes or groups of tribes by whom they were opened and worked.

The extent of the country in which the quarries occur precludes the possibility of all having been worked by a single group of tribes, nor is there reason to believe that all had been opened contemporaneously. The use of soapstone is thought to have developed in the north and to have advanced southward. Knowledge of the material and of the manner in which it could be employed would have passed from tribe to tribe, or from region to region. Centuries elapsed between the time the first soapstone was removed by the Indians from a mass in situ and the abandonment by them of the last quarry.

There are no known references in the early narratives to Europeans having witnessed the actual use of soapstone by the Indians, although it may have been known to the native tribes in some regions until contact with the whites.

One reference, in a book written nearly two centuries ago,[2] alludes to the use of soapstone utensils during an earlier generation, about the latter part of the seventeenth century. This was the work of the Swedish scientist, Peter Kalm, who wrote, when describing customs in New Jersey (vol. 1, pp. 343–344):

> A few of the oldest *Swedes* could yet remember seeing the *Indians* boil their meat in these pots. They are very thin, and of different sizes; they are made sometimes of a greenish, and sometimes of a grey pot-stone, and some are made of another species of apyrous stone; the bottom and the margin are frequently above an inch thick. The *Indians*, notwithstanding their being unacquainted with iron, steel, and other metals, have learnt to hollow out very ingeniously these pots or kettles of pot-stone.

This obviously referred to the use of soapstone vessels similar to others so widely distributed. But they were not in use when Kalm visited the Colony in 1749, and it is evident that the Indians of the region ceased making them soon after the establishment of the European settlements. Early narratives often referred to earthenware bowls and utensils of different forms being made and used by

[2] Kalm, Peter, Travels into North America. 2d ed., 2 vols. London, 1772.

the Indians, but no mention is known to have been made to the use of soapstone; consequently, the great majority of fragments of such vessels which are recovered from ancient sites are attributed to a period before the coming of the whites.

Another bit of evidence comes from a different source. Some 20 years ago archeological research in the Upper Tennessee Valley disclosed proof of three distinct periods of occupancy,[3] the most recent being that of the Cherokee. The form of burial practiced during the earliest of the three periods differed from the others. The graves were cylindrical and of small diameter, and the remains were forced into them after being closely bound with the chin between the knees. The name "Round Grave" was given to this culture by reason of the distinctive form of burial. Many fragments of soapstone vessels were found associated with material which belonged to the "Round Grave people"—the earliest recognized culture in the Upper Tennessee Valley—but no soapstone was encountered on sites attributed to the later inhabitants of the region. Certain types of objects which belonged to the "Round Grave people" connect them with "the Algonkian culture of the middle Atlantic seaboard and point to decided influence if not to actual relationship." This suggests that the knowledge of soapstone was carried southward by early Algonquian tribes who entered the region centuries ago and from whom other groups would have acquired the art of making soapstone vessels.

WORK AT THE QUARRIES

The quarrying of soapstone and the subsequent work necessary to create the finished vessels were evidently the most laborious tasks performed by the Indians who occupied or who visited the localities where the material was obtained. The quarries, so numerous and often of great size, extended for hundreds of miles from Alabama to New England and had been frequented by different tribes through many generations. Innumerable utensils had been formed at the quarries and later carried to the distant villages, but more pieces had been broken and left near the source of the stone. The latter, scattered over the ground, are now weathered to the same degree as is the exposed surface of the stone which remains in situ nearby.

In some localities rough, irregular pieces of stone were taken from the quarries, then trimmed and reduced to the desired size, and later fashioned into smoothed vessels. This appears to have been the practice when a new site was discovered, where pieces of stone protruded from the surface and were easily detached, but the same method

[3] Harrington, M. R., Cherokee and earlier remains on Upper Tennessee River. Indian Notes and Monogr., Mus. Amer. Indian, Heye Found, 321 pp., 1922.

was sometimes followed even though it was necessary to cut blocks from the solid mass.

The second and more characteristic way of shaping and removing the blocks was practiced when the stone was compact, relatively soft, and easily worked with the primitive tools. A spot was selected on the exposed surface of the soapstone, and the outline of the desired block was channeled, or rather grooved, by the use of stone implements. The groove was widened and deepened to the depth of the piece to be removed. During the preliminary cutting the block assumed the form of the intended vessel, often with projections at the ends which were later fashioned into lugs or handles.

Many stone implements have been discovered in the vicinity of the quarries which had been used in preparing the blocks of stone and later in trimming and shaping the utensils. Some are deeply weathered, indicative of age. A large number of the objects are made of quartzite, often crudely flaked boulders with slight secondary chipping. These differ in size; some are rather massive and heavy, and others are slender, chisellike implements. They appear crude, but were so formed to serve definite purposes during the process of shaping and reducing the blocks of stone.

When viewing an exposed surface of an ancient quarry, it is not difficult to visualize a scene that would have been presented centuries ago when the quarry was being worked by Indians. Some of the workers would have been engaged in cutting and removing blocks of stone from the mass, after the earth and mold had been cleared away; others would have been near the pits pecking and battering the pieces thus removed with crude stone implements, in the endeavor to hollow and shape the vessel. It was during this stage of the work that many partly formed vessels were broken and abandoned. The restoration of a typical scene at an ancient quarry is shown in plate 1, after a painting by E. G. Cassedy.

FINISHING THE VESSELS

After the outside of the vessel had been roughly shaped, the more difficult process of hollowing the inside was begun. This work resulted in many pieces being broken and abandoned as useless. It is evident that few, if any, vessels were carried from the vicinity of the quarry until after they had been entirely formed and were in a condition to be used, although the surfaces, both inside and outside, remained very rough and irregular. The finishing of the surface was accomplished at the village, after the return from the quarry, and obviously much of the smoothing resulted from the long use of the vessel.

The more compact and softer the stone the easier it could be worked, and consequently the more symmetrical the finished vessel, but, conversely, the more impure and less uniform the stone the more irregular and misshapen the vessel. This is proven by typical specimens recovered from widely separated quarries. Thus the nature of the stone rather than the skill of the workers often determined the quality of the utensils produced.

The majority of vessels from many quarries are rather long and narrow, having a length greater than the width, and being less in depth, with rounded sides and bottom. Handles extend from the narrow ends, some being placed well below the upper edge while others are at or very near the top. The two forms, restored diagrammatically, are shown in figure 1.

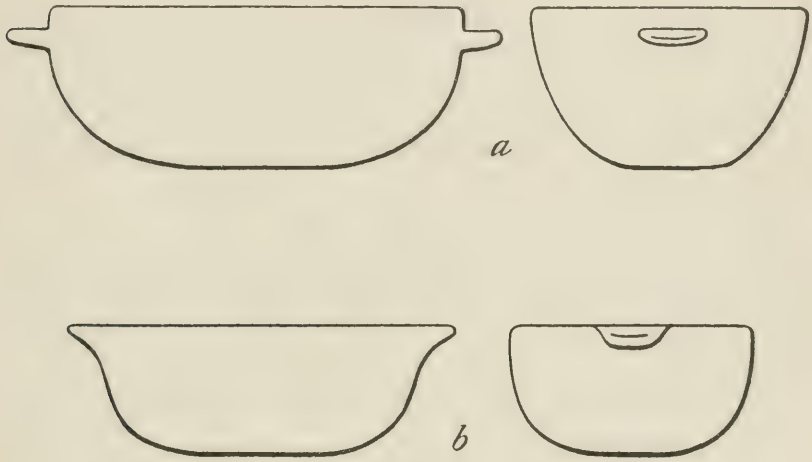


FIGURE 1.—Two types of handles shown diagrammatically.

Soapstone vessels varied in form and size as will be shown by photographs of specimens brought together from many sites and now preserved in the collections of the United States National Museum. However, some types found in other collections are not included in these illustrations, and many quarries, both large and small, are not mentioned in the text.

The first quarry to be described in detail, some 60 years ago, was located in Virginia, and later discoveries proved it to have been typical of others in Virginia and elsewhere.

Quarries in Virginia will now be briefly described, to be followed by references to some northward to New England, after which material from south of Virginia will be mentioned.

VIRGINIA AND NORTHWARD TO NEW ENGLAND

VIRGINIA

Professor Haynes in a short article some years ago [4] referred to the use of soapstone by the Romans and expressed the belief that the stone mentioned by Pliny was obtained from a quarry not far from Lake Como, near Chiavenne, the ancient Clavenna. The quarry was worked for many centuries. The stone was steatite or soapstone. As stated by Professor Haynes:

> The reference to Pliny will be found in his Natural History, book 36, chapter 44: "At Siphnos there is a kind of stone which is hollowed and turned in the lathe for making cooking utensils and vessels for keeping provisions; a thing that to my own knowledge is done with the green stone of Comum, in Italy."

Siphnos, an island in the Aegean Sea, was far distant from Comum, the present Como, in northern Italy. But soapstone was used wherever found. Thus we have two references to its use in making food vessels soon after the beginning of the Christian era, and it is easily conceived that it had been similarly employed during a much earlier period.

In concluding his article Professor Haynes wrote:

> Professor Baird, of the Smithsonian Institution, first directed attention to the site of a soapstone quarry worked for similar purposes by the Indians of our own country. This is at Chula, Amelia County, Va., and it has been thoroughly explored and described by Mr. F. H. Cushing in the Smithsonian Report for 1878.

Amelia County.—As told in the report prepared by Secretary Baird: [5]

> During the spring of 1875, some specimens of steatite were received from the quarry of John B. Wiggin, in Chula, Amelia County, Va. Among these were fragments of rude vessels, which from their number and unfinished condition, were regarded as indicating that the place in question was once an aboriginal mine * * *
>
> Inasmuch as, at the time, no quarry of this kind had been discovered, and as, moreover, aboriginal methods of mining and working pot-stone were entirely unknown, it was thought advisible to have a careful exploration of the place undertaken, which was intrusted to Mr. F. H. Cushing, who visited the locality in June last [1877], causing excavations of sufficient extent to be made to reveal a large portion of the rock surface worked by the Indians.

Shallow excavations 10 to 70 feet in diameter, filled with vegetal mold, indicated the quarries of the Indians. A space about 40 by 60 feet was cleared, and "everywhere over the rock surface, thus exposed,

[4] Haynes, Henry W., Notes upon ancient soapstone quarries, worked for the manufacture of cooking utensils. Proc. Amer. Antiq. Soc., n. s., vol. 2, pt. 3, p. 364, Apr. 25, 1883.

[5] Ann. Rep. Smithsonian Inst. for 1878, pp. 44–45, 1879.

he found grooves and hollows made by the Indians in taking out sugarloaf-shaped masses of the rock; and throughout the soil removed he found numerous fragments of the masses mostly hollowed as the beginning of pots, together with numerous quartz picks, some broken axes and mauls, and a few hammers of soapstone, which had been used in quarrying and working the material."

Three of the many speciments collected by Cushing and now in the United States National Museum are illustrated in plate 5.

Goochland County.—During the spring of 1881 George W. Reid, writing from Caledonia, Goochland County, to Professor Baird, described one or two extensive quarries of soapstone in that county. They were known locally as "Payne's Quarry or the Indian Dens," and were evidently similar to those some 30 miles southward in Amelia County. At that time, 1881, part of the surface of the quarry had been cultivated, but much of it remained covered with brush. Many specimens, some of which were in a more finished condition than usual, were found in the vicinity of the quarries. One bowl, recovered from the bed of the creek, was 15 inches in length and weighed about 40 pounds. There was likewise discovered "an axe and a broken bowl lying just as they had been left by the Indians." Material collected by Reid at that time is in the National Museum.

Bedford County.—A large quarry workshop occurs on a ridge a few miles southeast of Bedford, between Little Otter and Big Otter Rivers, near the junction of the streams. No excavations have been made to ascertain the extent of the work done by the Indians. Many fragments of unfinished vessels, intermingled with quantities of unworked stone, have been found scattered over the surface. A view of the site, looking along the ridge and showing piles of stone, is reproduced in plate 3.[6] Examples of the unfinished, broken vessels are shown in plate 2. They form an interesting series and illustrate clearly the work done at the quarry. All are greatly weathered and show the effect of long exposure to the elements. One specimen that, if completed, would have been a long narrow vessel with handles extending from the rim, is shown, restored, in figure 2.

Albemarle County.—In 1926 extensive quarries were being operated by the Virginia Alberene Corporation in the vicinity of Schuyler, Nelson County, Va. One of the quarries is shown in plate 4, figure 1. Another quarry was soon to be opened about 2 miles northeast of Schuyler, on a high ridge a short distance south of Damon, in Albemarle County. This was the site of an ancient Indian quarry and was between 5 and 6 miles from the nearest point on the left bank

[6] I am indebted to R. L. Updike, Bedford, Va., for all information concerning the quarry and for the photograph. The six specimens from the site were presented by Mr. Updike to the U. S. National Museum.

of James River. The site was visited at that time and proved to be of interest:[7]

Here great masses of soapstone, outcropping on the surface, follow the general direction from southwest to northeast and have a dip of about 60° to the southeast. The area is heavily timbered, the surface very irregular and broken, with one or more springs nearby. For a distance of nearly a thousand feet along the ridge it is possible to trace pits dug by the Indians, generations ago, when getting soapstone. More than 20 such excavations were discovered, the majority being within the northern half of the distance, and becoming less clearly defined southward. They vary in diameter from 10 to 30 feet and at present are from 2 to 4 feet in depth, some are distinctly separated while others merge and may in reality be parts of a greater excavation. The surface surrounding the pits is covered with pieces of stone which had evidently been rejected and thrown from the quarries, but now all is covered with thick vegetal mold, the spaces between the pieces are filled, and very little of the stone is visible between the mold and moss. The ancient pits are similarly covered and consequently it was not possible to ascertain the actual extent of the quarries.



FIGURE 2.—Virginia. Part of a vessel from the quarry near Bedford, restored to show probable shape if it had not been broken. U. S. N. M. No. 379261.

Depressions at the Indian quarry are shown in plate 3.

Typical examples of the broken and partly made vessels were collected and are now in the National Museum. One unusually complete specimen is illustrated in plate 5, figure 3. Several crude quartzite implements that had been used in shaping the blocks of stone were encountered near the pits.

Some years ago a very large quarry was operated a few miles north of those now being worked near Schuyler and Damon, but it was later abandoned. The excavations appear larger than any of the more recent quarries, and when they were last visited by the writer, huge blocks of stone weighing several tons each were piled on the surface nearby, covered with vines and lichens, and suggested an ancient

[7] Bushnell, David I., Jr., Ancient soapstone quarry in Albemarle County, Virginia. Journ. Washington Acad. Sci., vol. 16, No. 19, pp. 525–528, Nov. 18, 1926.

Pelasgic ruin. The stone, which was probably the same as that worked by the Indians at the quarry workshop near Damon, was analyzed and described in 1895. Part of the account may be quoted.[8]

> The "soapstone" at the first-named locality [Alberene, Albemarle County, Va.] is not a pure steatite, but rather an admixture of various alteration products, among which a colorless tremolite and light-green talc are most conspicuous. What the original rock may have been is not apparent from a study of thin sections, but the appearance in the field is such as to suggest it to have been a pyroxenite. It occurs in the form of a broad dike or sheet, parallel and dipping with the gneiss (?) in which it is inclosed, and, as displayed in the quarry opening, is traversed by numerous irregular veins of coarsely crystalline calcite. The rock is very massive, in general appearance eminently suggestive of an eruptive pyroxenite which has undergone extensive hydration and carbonatization, whereby a considerable portion of its calcium has separated out in the form of calcite. As is almost invariably the case in rocks of this class, the mass is traversed by numerous joint planes, some of which are pronouncedly slickensided.

The following note was attached to the preceding and refers to stone from the Alberene quarry:

> A chemical analysis of the stone, by R. L. Packard, yielded SiO_2, 39.06 percent; Al_2O_3, 12.84 percent; FeO, 12.93 percent; CaO, 5.98 percent; MgO, 22.76 percent; ignition, 6.56 percent. Total 100.13. All iron calculated as FeO.

Fairfax County. One of the most interesting ancient quarries in Virginia, and certainly the one most carefully examined and studied, was located about 2 miles northwest of Clifton and 22 miles west of Washington. The steatite was exposed in the bed and on the banks of a small branch of Bull Run and varied in thickness from 20 to 50 feet.

The examination of the quarry was begun late in March 1894[9]—

> and in a few weeks a most striking illustration of the enterprise and skill of our aboriginal tribes was exposed to view. A trench or gallery some 25 feet wide and reaching in places a depth of 16 feet had been carried into the face of the hill to a distance of 60 or 70 feet, and a second pit, inferior in dimensions, had been opened beyond this. Almost the entire excavation had been carved out of the solid steatite by means of stone picks and chisels, and all the evidence of the cutting and sculpturing—even the whitened surfaces of the tool marks—were as fresh as if the work of yesterday * * *.
>
> Much impure stone had been cut away in efforts to reach the purer masses, and this was a most laborious work * * * The whole surface, with its nodes and humps and depressions, covered everywhere with the markings, groovings, and pittings of the chisel, presented a striking example of the effectiveness of native methods and the persistence of native effort.

Quantities of unfinished vessels, broken during the process of shaping, were recovered from the site; also a great number of stone implements, large and small, which had been used in trimming the blocks

[8] Merrill, George P., Notes on asbestos and asbestiform minerals. Proc. U. S. Nat. Mus., vol. 18, pp. 281–289, 1895.

[9] Holmes, W. H., Stone implements of the Potomac-Chesapeake tidewater province 15th Ann. Rep. Bur. Ethnol., pp. 13–152, 1897.

of stone. A photograph of the quarry as it appeared in 1894, soon after the beginning of the examination, is reproduced in plate 4, figure 2. Two specimens from the quarry are shown in plate 5, figure 1. Both are parts of unfinished vessels and reveal clearly the marks left by the stone implements used in shaping the blocks of stone.

Finished vessels.—There are many localities in Virginia where soapstone was obtained by the Indians in prehistoric times, and some of the more important of these have now been mentioned, but other quarries of equal extent and interest may remain hidden beneath moss and vegetal mold to be revealed at some later day.

The vast amount of work that was done at the quarries is indicated by the numerous excavations in the stone, and by the quantities of fractured, partly made vessels that have been encountered nearby. And although many were broken at the quarries, others were com-

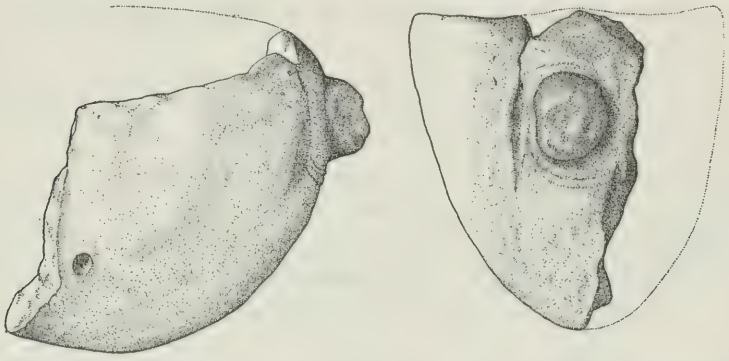


FIGURE 3.—Virginia. Part of a soapstone vessel found on the site of Nandtanghtacund, on right bank of the Rappahannock River, Caroline County. U. S. N. M. No. 378093. One-third natural size.

pleted and carried away to be fashioned into comparatively symmetrical, smoothed vessels. This is revealed by the few entire specimens, and the many fragments of such utensils, that have been found on the sites of ancient villages. Three examples, all discovered on ancient sites in the James River valley, are illustrated in plate 6.

No entire soapstone vessel is known to have been recovered in the valley of the Rappahannock, but fragments of finished utensils are numerous. One piece of exceptional interest was found at the edge of the water of Port Tobago Bay, on the right bank of the Rappahannock, in Caroline County. This was the site of the village of Nandtanghtacund in 1608. Two views of the specimen are shown in figure 3. The projection, of which there was probably a duplicate at the other end of the vessel, had been cut to represent a human head or face.

DISTRICT OF COLUMBIA

In the Smithsonian Report for 1878 Professor Baird first described the soapstone quarry at Chula, Amelia County, Va., and then continued:

> Attention being drawn to these explorations while in progress by notices in some of the Washington newspapers, Mr. Elmer R. Reynolds, of this city, brought to notice some similar specimens of vessels which he had found within the District, on Soapstone Run, a branch of Rock Creek.

The quarry was located just north of the present Bureau of Standards, on the summits of two adjoining hills 100 yards or more apart and separated by a small stream known as Soapstone Run. The hills were partly removed in 1891, when Connecticut Avenue was extended northward, and were more greatly reduced a few years ago when Albemarle Street was graded from east to west across the avenue.

The quarry was discovered by Reynolds during the summer of 1874.[10] The surface was covered with brush, ferns, and fallen leaves, with quantities of soapstone scattered about and "hundreds of fragments cropped out through the leaves, nearly every one of which showed well defined traces of having been worked" by the Indians.

Reynolds worked on the south hill, and in 1890 Holmes did similar work on the north hill, finding quantities of broken, unfinished vessels, together with innumerable stone implements which had been used in and about the quarry.[11]

In a later account of the quarry and of the material found, Holmes referred to the method of making soapstone vessels and drew this conclusion:[12]

> So far as the evidence obtained on the site shows, work was confined almost exclusively to procuring material for use in vessel making, but apparently the pots were not often shaped or even partly shaped in place, to be afterward detached by undercutting and wedging as observed in many other places. It appears that as a rule the rough block was first obtained, then trimmed down to the approximate size and form, and afterward hollowed out ready for the finishing operations, which were in most cases conducted elsewhere. There were naturally many failures from breaking, from splitting along partially developed cleavage planes, and from imperfections in texture; and many hundreds of these failures yet remain on the site, in the pits, in the heaps of debris, and scattered far down the slopes of the hill and along the stream bed.

Northward from the District of Columbia, soapstone is plentiful in Maryland, and many quarries were opened by the Indians on

[10] Reynolds, Elmer R., Aboriginal soapstone quarries in the District of Columbia. 12th Ann. Rep. Peabody Mus. Arch. and Ethnol., vol. 11, No. 3, pp. 526–535, 1880.

[11] Holmes, William H., Excavations in an ancient soapstone quarry in the District of Columbia. Amer. Anthrop., vol. 3, pp. 321–330, October 1890.

[12] Holmes, William H., Stone implements of the Potomac-Chesapeake Tidewater province. 15th Ann. Rep. Bur. Ethnol., pp. 13–152, 1897.

both sides of the Patuxent River in the present Howard and Montgomery Counties. Quarries have likewise been discovered in the adjoining counties of Baltimore and Carroll, and large collections of partly made vessels from the sites are preserved in the National Museum. Two specimens are shown in plate 7.

Ancient quarries and quantities of fragments of soapstone vessels have been discovered in York, Lancaster, and Chester Counties, Pa. The three counties adjoin Maryland on the south, and the material from the entire region is similar. One vessel from Lancaster County is illustrated in plate 7. Fragments of soapstone utensils found on sites farther up the valley of the Susquehanna, in Juanita and Clinton Counties, are in the collections of the National Museum, also some pieces from near Easton, on the Delaware River in

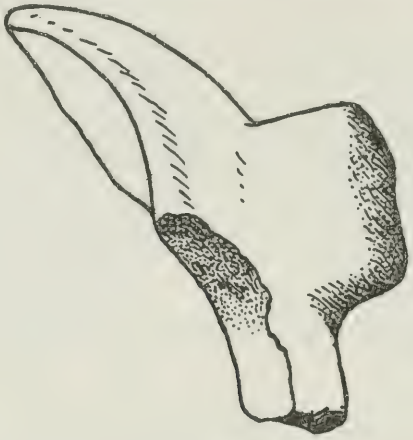


FIGURE 4.—New York. Part of a small vessel from Jefferson County. U. S. N. M. No. 8903. Natural size.

Northampton County, which proves the wide distribution and general use of the stone.

Soapstone was used extensively by the Indians who once occupied the present State of New York. A piece of a small bowl, found in Jefferson County, is shown in figure 4. The handle, which projects from the side of the vessel below the rim, resembles specimens from Virginia and elsewhere.

EASTWARD FROM THE HUDSON RIVER

Soapstone occurs in the Connecticut Valley, and the quarries which were operated in that area by the Indians were undoubtedly the source of the material found on nearby sites. An interesting and apparently very old quarry was discovered in 1892 at Bristol,

Hartford County, west of the Connecticut River. The quarry was briefly described in a letter written by F. H. Williams to W. H. Holmes. It read in part:

BRISTOL, CONN., *June 28, 1892.*

Bristol has always known of an old Indian soapstone quarry in its limits. From its surface many articles have been gathered. A man has recently begun the construction of a road across the face of the side hill over the quarry. He has uncovered under 4 feet of solid earth a sloping side of the rock, upon which are a number of vessels all blocked out, ready to be cut away. The peculiarity of the thing is in the extreme depth beneath the soil in which they lie on the solid ledge. Above is towards one foot of mold black, and then 3 or 4 feet of solid loam * * * I can not keep it long from being blasted, but shall photograph it * * *

Photographs of the quarry were made and one is reproduced in plate 8. An oval piece of stone, shaped and ready to be removed, is clearly visible in the lower left corner of the picture.

Vessels, large and small, made of soapstone, were used by the native tribes of eastern Massachusetts, and fragments of such utensils have been found on widely separated sites. One example from Bristol County, which touches Rhode Island on the west, is shown in plate 7. This may have come from the large quarry at Johnston, a short distance westward in the latter State.

On December 4, 1879, a committee of the Rhode Island Historical Society presented a report on the soapstone quarry which was opened in February 1879, "in Johnston, R. I., about one-eighth of a mile west of the Greek Tavern, north of the Hartford turnpike."

The several pits, the largest of which measured about 10 by 6 feet, and 5 feet in depth, were filled with vegetal mold and pieces of stone, and in the largest pit were encountered "some whole stone pots, some partly finished pots, some only blocked out, numerous stone hammers, and horns of a deer, the bones of an animal and a few shells. * * * The sides and bottom of this excavation contain about 60 distinct pits and knobs of places where pots and dishes were cut from the rock."

The quarry must have been of great size, and the report states that "from the excavations and their surroundings have been removed about three hundred horse cart loads of stone chips left by the Indian workmen." The quarry, with other known sites, was described by Putnam.[13]

SOUTHWARD FROM VIRGINIA TO THE GULF OF MEXICO

Having sketched the distribution and use of soapstone from Virginia to the Connecticut Valley and eastward, it will now be of

[13] Putnam, F. W., The manufacture of soapstone pots by the Indians of New England. 11th Ann. Rep. Peabody Mus., p. 273, 1878.

interest to return to Virginia and refer, briefly, to the occurrence of similar material southward to Tampa Bay.

Conditions in North Carolina are not different from those encountered in Virgina. Four stone vessels from the western part of the State are illustrated in plate 9. In addition to these the National Museum collections include many fragments of soapstone utensils from other western counties, and from Stanly and Franklin Counties in the central part of the State; also specimens from a village site one mile northeast of Stella, Carteret County, on the Atlantic coast. Thus it is possible to trace the use of soapstone across the entire width of the State, from the mountains to the sea.

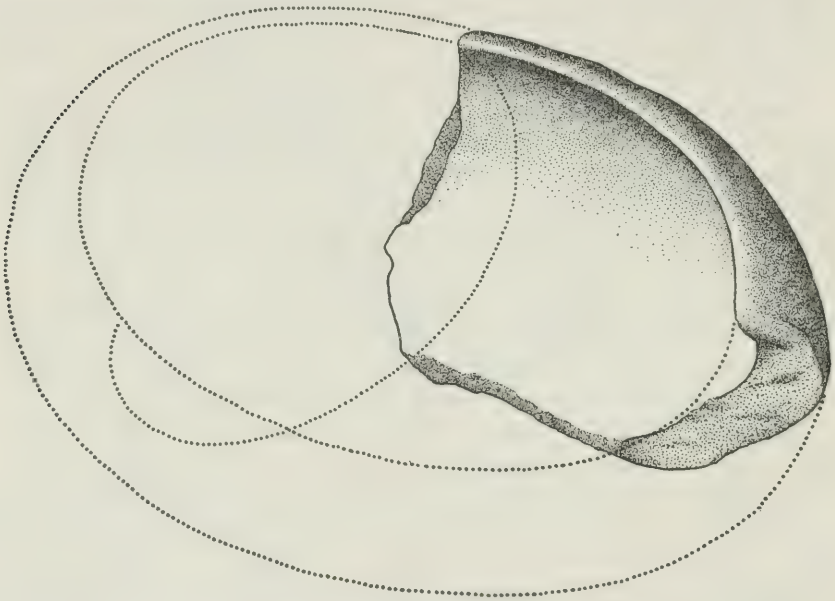


FIGURE 5.—Tennessee. Fragment of a vessel, Cocke County. U. S. N. M. No. 34748.

Much material has been recovered from village sites in eastern Tennessee. One fragment, from Cocke County which touches the North Carolina line, suggests the large vessel from Burke County in the latter State. A drawing of this vessel, restored as suggested by its form, is shown in figure 5. The two localities are only a short distance apart, and the specimens undoubtedly belonged to the same period.

Decorated soapstone vessels are seldom found, and consequently fragments of two examples from South Carolina are of much interest. Both are shown in figure 6. One is a rim fragment with a handle extending from the edge. The entire surface is smoothed and polished. The flat surface of the handle, flush with the edge

of the vessel, is decorated with incised lines. The second piece is a small fragment, decorated with incised lines. This is similar to a specimen found with material attributed to the "Round Grave people" in Loudon County, Tenn.[14] Both are decorated with undulating lines, rather broad and shallow, and both appear to be equally old.

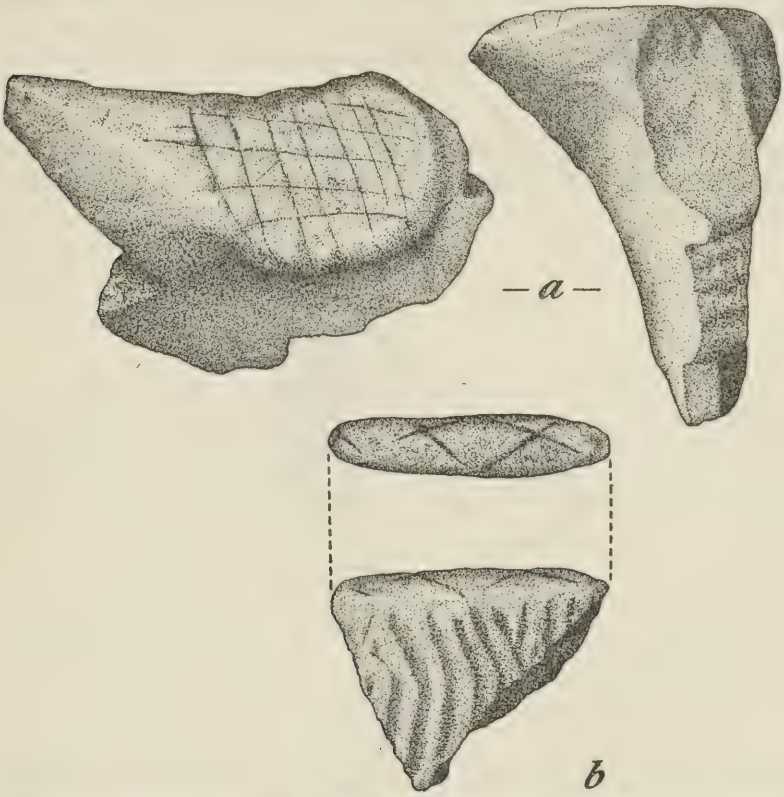


FIGURE 6.—South Carolina. Two fragments of decorated soapstone vessels. *a*, Chester County. U. S. N. M. No. 91843. *b*, Anderson County. U. S. N. M. No. 34905. Natural size.

Ancient soapstone quarries in Alabama had been recognized as such some years before others in Virginia had been discovered and described. Examples of large broken vessels from the quarry workshop near Dudleyville, Tallapoosa County, are in the National Museum collections. Also one complete vessel, crudely made with handles roughly shaped. A drawing of one handle is reproduced in figure 7. Although very rough and irregular, the vessel had been used, and it appears to be very old, as shown in plate 10.

[14] Harrington, op. cit., fig. 16, p. 151.

Similar material has been discovered in Georgia, and fragments of beautifully made utensils have been found on sites in the upper Savannah Valley.

Soapstone or steatite does not occur in situ in Florida, and the nearest deposits are northward in central Alabama. Consequently, all soapstone vessels found in Florida had been carried from some distant point. Two remarkable specimens from Florida are illustrated in plate 10. No similar pieces are known.

CONCLUSION

The occurrence of steatite or soapstone in the Eastern United States, from New England southward to Alabama, furnished the



FIGURE 7.—Alabama. Detail of vessel from Tallapoosa County. U. S. N. M. No. 32280.

native tribes with a material which could be worked with their primitive stone tools. The extent to which it was utilized is revealed by the quarries and quantities of broken, unfinished vessels that have been discovered and by the many fragments of finished utensils encountered on ancient village sites.

Soapstone was used in the far North, and the knowledge of its adaptability for making utensils, and the comparative ease with which it could be worked, may have been brought from the North by early Algonquian tribes and later communicated from tribe to tribe until it became known to all by whom it could be obtained. This is suggested by discoveries in Tennessee, previously mentioned when referring to the age of the quarries, and if the hypothesis is correct,

the stone was used in the North long before it was quarried in the South. Consequently, some of the utensils found in New England may be much older than similar pieces discovered in the valley of the Savannah, but it is not possible at this time to even approximate the age of the material.

The quarries which have been discovered throughout the region where the stone occurs are similar to those which have been described in the Piedmont Plateau of Virginia and in the District of Columbia, differing only in extent and the composition of the stone. The quarries, so widely distributed, were obviously the work of many different tribes, but the descriptions of the Virginia and District of Columbia quarries are applicable to all—which indicates that a custom, or practice, developed by one group would in time be transmitted to others, often far distant and unrelated.

EXPLANATION OF PLATES

Plate 1

Work at an ancient soapstone quarry as suggested by discoveries made at the quarry near Clifton, Fairfax County, Va. Three phases of the work carried on at the quarry are shown in the group: Shaping the stone before removal from the mass, taking the block from the quarry, and beginning the process of hollowing the block to form the vessel. Painted by E. G. Cassedy, of the Bureau of American Ethnology.

Plate 2

Unfinished vessels from the Bedford County quarry, Va.

1. *a*, Block of stone as removed from the quarry. The flat top surface had been detached from the mass. Size 11¾ by 7⅞ inches, depth 5¾ inches. U. S. N. M. No. 379258. *b*, A block similar to *a* but having a slight concavity, the beginning of the hollowing. Size 12 by 7⅜ inches, depth 4½ inches. U. S. N. M. No. 379259.
2. Parts of two vessels broken while being hollowed, both designed to have flat bottoms. *c*, Length 15½ inches. U. S. N. M. No. 379260. *d*, Depth 4½ inches. U. S. N. M. No. 379261. A sketch of this vessel as restored is shown in text figure 2.
3. Fragments of two partly finished vessels intended to have rounded bottoms. *e*, Depth 5⅜ inches. U. S. N. M. No. 379262. *f*, Width 12 inches, height at handle 5½ inches. U. S. N. M. no. 379263.

Plate 3

Ancient soapstone quarries in Virginia.

1. A view of the ancient soapstone quarry southeast of Bedford, Bedford County, Va. It is on a ridge between Little Otter River and Big Otter River, near the junction of the streams. Photograph by R. L. Updike.
2. One of the large pits or excavations, now filled with mold, at the ancient quarry south of Damon, Albemarle County, Va.
3. Another pit at the quarry near Damon, with pieces of soapstone scattered over the surface.

PLATE 4

Modern and ancient soapstone quarries in Virginia.

1. Soapstone quarry operated by the Virginia Alberene Corporation. It is south of Damon, Albemarle County, near the Nelson County line. Photographed September 1928.
2. Ancient quarry near Clifton, Fairfax County, Va. Examined and photographed during the spring of 1894.

PLATE 5

Unfinished vessels from Virginia quarries.

1. Fairfax County. From quarry near Clifton, 1894. *a*, Size 9½ by 6 inches. *b*, Size 6½ by 3 inches. U. S. N. M. No. 150368.
2. Amelia County. From the first quarry described in Virginia, near Chula, 1877. *a*, Size 7½ by 7 inches. U. S. N. M. No. 31555. *b*, Size 4 by 3 inches. U. S. N. M. No. 31552. *c*, Size 9 by 7 inches. U. S. N. M. No. 31556.
3. Albemarle County. From quarry near Damon, 1926. Size 16 by 8½ inches. U. S. N. M. No. 332023.

PLATE 6

Finished vessels from sites in James River Valley, Va.

1. Goochland County. Now in the Valentine Museum, Richmond. Size 6 by 4 inches.
2. Fluvanna County. Found near the mouth of the Rivanna, at Columbia. Size 9½ by 5½ inches. U. S. N. M. No. 136085. Goochland and Fluvanna Counties adjoin, on the left bank of the James River.
3. Buckingham County. Restored from fragments collected by Maj. Wirt Robinson on a site near the foot of Buck Mountain. They were found over a period of many years when some pieces would be uncovered by the plow and others exposed by the rain. Size 18¾ by 12¼ inches. U. S. N. M. No. 342083.

PLATE 7

Vessels from Pennsylvania, Maryland, and Massachusetts.

1. Pennsylvania. Crudely made vessel from Lancaster County. Size 12 by 7 inches. U. S. N. M. No. 17236.
2. Maryland. *a*, Baltimore County. Size 16½ by 14½ inches. U. S. N. M. No. 208361. *b*, Carroll County. Size 12½ by 5 inches deep. U. S. N. M. No. 208353.
3. Massachusetts. Bristol County. Size 9½ by 5 inches. U. S. N. M. No. 17972. Greatly worn from use.

PLATE 8

Ancient soapstone quarry near Bristol, Hartford County, Conn. The quarry was exposed and photographed in 1892. Many stone implements which had been used in working the stone were discovered at the site.

PLATE 9

Finished vessels from North Carolina.

1. Burke County. The specimen is complete, rather symmetrical, and without handles. It shows the effect of long use. Size 15 by 12 inches. U. S. N. M. No. 35644.

2. *a*, Wilkes County. Size 14 by 9½ inches. U. S. N. M. No. 339003. *b*, Caldwell County. Size 11¾ by 7¾ inches. U. S. N. M. No. 82912. Wilkes and Caldwell are adjoining counties and are within the old Cherokee country.
3. Mitchell County. Size 16½ by 11 inches. U. S. N. M. No. 27016. This is an unusually massive, rough vessel, and although it may not have been finished it had been used.

PLATE 10

Finished vessels from Florida and Alabama.

1. Florida. Putnam County. Collected by Prof. S. F. Baird in 1877. The vessel is symmetrical, of uniform thickness, and smoothed from use. The rim is hexagonal in outline, wall divided into six well-defined sections. Size 8½ by 4½ inches. U. S. N. M. No. 30217.
2. Florida. Found on Pinellas Point, Pinellas County, on the north side of Tampa Bay, 1869. The stone is soft and the walls are thin and very rough. The vessel may not have been finished. A small circular base permits it to be placed in an upright position. Size 14½ by 7½ inches. U. S. N. M. No. 7974.
3. Alabama. A large rough vessel found in Tallapoosa County. Size 11½ by 7 inches. U. S. N. M. No. 32280. A detail of the vessel, showing one handle, is given in text figure 7.



ANCIENT SOAPSTONE QUARRY.



1. Bedford County.



2. Bedford County.



3. Bedford County.

UNFINISHED VESSELS FROM ANCIENT SOAPSTONE QUARRY IN VIRGINIA.

(For explanation, see p. 487.)



1. Bedford County.



2. Albemarle County.



3. Albemarle County.

ANCIENT SOAPSTONE QUARRIES IN VIRGINIA.

(For explanation, see p. 487.)



1. Albemarle County.



2. Fairfax County.

MODERN AND ANCIENT SOAPSTONE QUARRIES IN VIRGINIA.

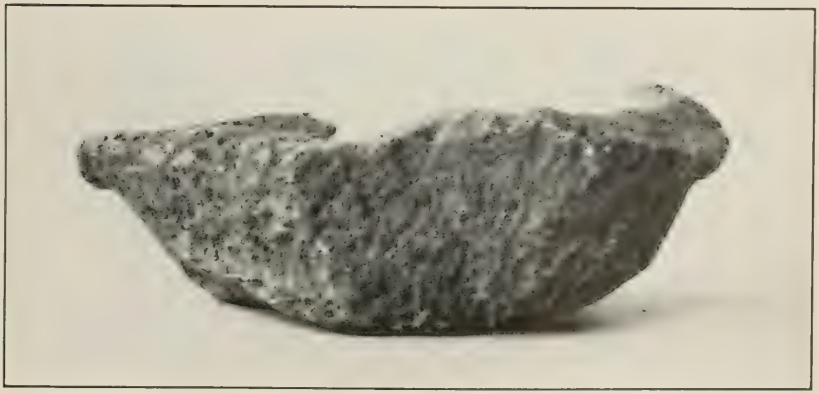
(For explanation, see p. 488.)



1. Fairfax County.



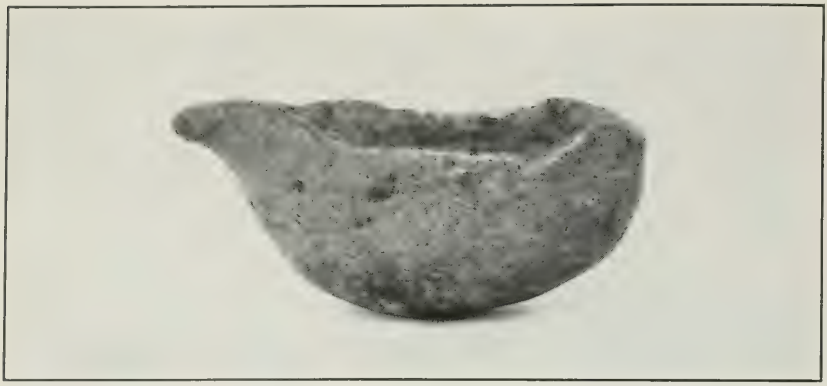
2. Amelia County.



3. Albemarle County.

UNFINISHED VESSELS FROM ANCIENT SOAPSTONE QUARRIES IN VIRGINIA.

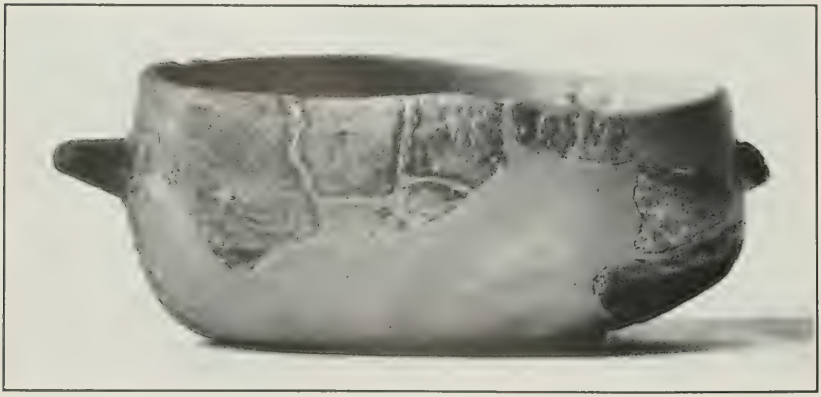
(For explanation, see p. 488.)



1. Goochland County.



2. Fluvanna County.



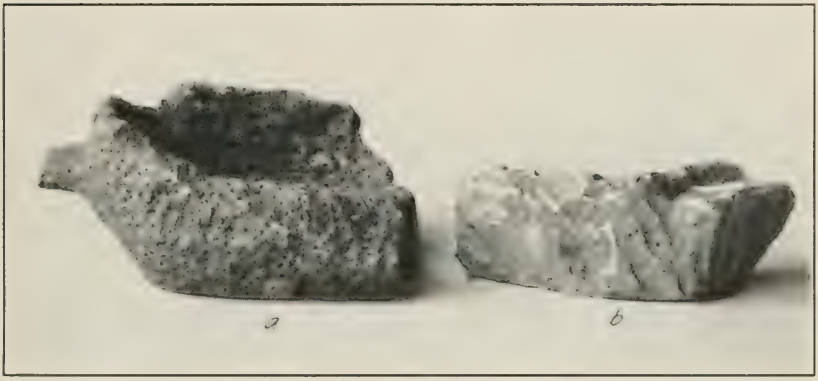
3. Buckingham County.

FINISHED VESSELS FROM SITES IN JAMES RIVER VALLEY, VA.

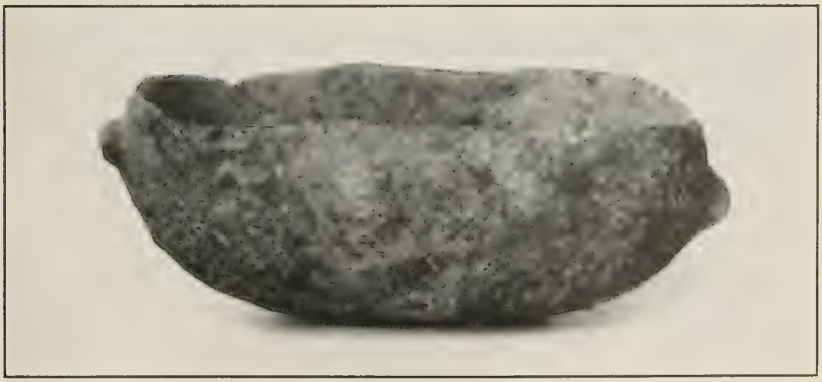
(For explanation, see p. 488.)



1. Pennsylvania. Lancaster County.



2. Maryland. *a*, Baltimore County; *b*, Carroll County.



3. Massachusetts. Bristol County.

VESSELS FROM PENNSYLVANIA, MARYLAND, AND MASSACHUSETTS.

(For explanation, see p. 488.)



ANCIENT SOAPSTONE QUARRY, HARTFORD COUNTY, CONN.



1. Burke County.



2. *a*, Wilkes County; *b*, Caldwell County.



3. Mitchell County.

FINISHED VESSELS FROM NORTH CAROLINA.

(For explanation, see pp. 488–489.)



1. Florida. Putnam County.



2. Florida. Pinellas County.



3. Alabama. Tallapoosa County.

FINISHED VESSELS FROM FLORIDA AND ALABAMA.

(For explanation, see p. 489.)

THE MODERN GROWTH OF THE TOTEM POLE ON THE NORTHWEST COAST[1]

By Marius Barbeau

Dominion Ethnologist, National Museum, Ottawa, Canada

[With 5 plates]

Totem poles were once a characteristic form of plastic art among the tribes of the northwest coast, in British Columbia and southern Alaska. The natives took pride in them and strained every nerve to make them worthy symbols of their own social standing and achievements.

But the carvers were not artists in our present meaning of the term; they were not permitted to give free rein to their imagination or fancy. They had nothing to do with the choice of the cedar tree they were to carve, nor the spot in the village where it was to be erected after it was carved, nor even the selection or the number of the figures they were hired to execute. Their art was not considered esthetic; it was useful. Regulated by custom, it fulfilled a social purpose and was the chief vehicle of a system of heraldry which in a short time grew to abnormal proportions. Hence its vital importance in the life of the natives.

The totems: what they were.—The totems, whose figures appear on the poles, were not, as often misrepresented, pagan gods or fetishes, nor did they usually stand for clan ancestors. Their spiritual significance was quite secondary; they were not worshipped or even revered for their own sake. First of all they were symbols in the nature of European coats of arms or badges of ownership, and they usually illustrated historic events, true or fictitious.

When a new totemic emblem was introduced—this happened only seldom—an explanation of its origin and significance was furnished; this was purely stereotyped. The people were not credulous enough to believe their own tales, nor presumably most of the other folk at large.

The Raven, the Wolf, the Grizzly Bear, the Blackfish, the Eagle, and the Thunderbird were six of the outstanding totems of the

[1] Reprinted by permission, with slight revisions by the author and the addition of some illustrations, from the Journal of the Washington Academy of Sciences, vol. 28, No. 9, Sept. 15, 1938.

North Pacific coast. They were used in most places from Alaska to the Strait of Georgia. Yet hardly any effort was made to explain how they had become the exclusive badges of definite families. They were hereditary and taken for granted. Nor was a Raven or a Wolf god supposed to exist in that country. At best, the Raven was a culture hero of ancient folk tales, quite apart from heraldry. And I wonder whether the Eagle emblem, admittedly recent, is not a mere imitation of the Russian imperial crest. Like that crest, it often appears as a double-headed eagle, and it originated in the country occupied by the Russians, about the time of their occupation.

When a stereotyped explanation is given of the origin of an emblem, it runs like this:

A man named Small-Frogs long ago was starving with his family, up the Nass. As he stood at the edge of the lake, a monster emerged from the water—Large-Eyes, with a huge human face. Assisted by his human family, he cut this being in half and succeeded in pulling the upper part of its body out of the water. Later he gave a feast to the people, and adopted Large-Eyes as an emblem. It was represented pictorially with a large human face and a body without legs—just a trunk.

A story of this kind was of little importance to the people. What mattered was the feast given and the presents distributed to confer prestige upon the emblem which was supposed to illustrate it. Without this consecration no emblem ever came into existence, for it would have had no status, no social recognition. It would have been an object of ridicule.

The figures or totems most commonly used, besides the above-mentioned, were those of familiar animals: the Frog, the Beaver, the Mountain Goat, the Shark, the Halibut, the Owl, and the Starfish. A number of other themes, localized, were derived from the fauna, the flora, and the traditions of the country. The Fireweed and the Water Lily were used as crests by at least two clans of the Haida and the Tsimsyan. Such phenomena as the Rainbow, the Stars, the Earthquake, the Glacier, casually appeared in the list of clan and personal badges. Among many odd crests we find the White Man's Dog, the Palisade and the Wagon Road, Captain Vancouver, Russian Priests, and Guardian Angels.

The totem poles: where and how they stood.—There were carved house poles, grave posts, and totem poles proper, detached, that stood in front of the houses, and others that served as house-front entrances. Smaller poles with grave boxes were also found among some of the tribes, mostly in the southern districts. House-front paintings, carved house posts, and graveyard structures were more ancient than detached poles. The detached totem poles as a fashion were fairly recent.

The village houses stood in a row along the waterfront, usually close to the edge of the water, either in the coves or along the rivers. The Tsimsyan were the only people of the true northwest coast nations whose habitat consisted of rivers as well as of the adjacent seacoast. The villages of two of their subnations (the Niskæ and the Gitksan) were situated exclusively on two rivers—the Nass and the Skeena—on the Canadian side, close to the Alaskan boundary. It is only there that we find totem poles away from the coast, up the rivers as far as 250 miles from the tidewaters.

The detached poles stood in a row a few feet in front of the owners' houses. They extended the whole length of the village, in an impressive, though irregular, row of carved columns sometimes surmounted by detached figures of birds, animals, and people.

Totem poles until recently stood along the village fronts of only a few nations in the north: the Haida of the Queen Charlotte and Prince of Wales Islands, the Nass River people, the upper Skeena tribes, and the southern Tlingit of Alaska. Elsewhere they were either nonexistent or very few, or very recent, as among the Kwakiutl. The only way of showing the owners' crests where poles did not exist was by means of painted designs on the house fronts, or a few carved portals.

A pole was left to stand as many years as nature would permit. Sometimes two or three poles belonged to the same family, but had been erected at different times as memorials to chiefs after their death, one generation apart from the other. They stood side by side and were part of the village cluster. Some of the poles leaned to one side, ready to fall, sometimes supported by props. It was not the custom to mend or transplant a pole, however precarious its condition. Once fallen, it was pushed aside, if it were in the way; it decayed gradually or was cut up and burned as firewood.

The totem poles of the Haida of the Queen Charlotte Islands and Alaska, and of the Niskae of the Nass River, have mostly fallen and disappeared, or they have been removed to museums and parks abroad. Some of the Tlingit poles, on the Alaskan coast, have been moved away from the old village sites to Ketchikan, Sitka, and other modern towns and are being preserved there, usually under a gaudy coat of modern paint. The only collection that is still fairly intact is that of the Gitksan tribes, on the upper Skeena River, in northern British Columbia. It consists of over 100 poles, in isolated village groups of from a few to about 30, in the 8 tribal villages of the upper Skeena. Some of these are also being preserved by the Canadian Government and railways.

The natives, many years ago, abandoned their old villages and moved to new quarters. The old village sites are now deserted; the plank houses have fallen in, and the totem poles were forsaken in

those former abodes of native life. They fall down and decay, while others lean precariously or totter in the wind, soon to come down with a crash. A few of the finest clusters, among the Tsimsyan, were willfully destroyed in recent years. They reminded the modern villagers too much of their breechclout ancestors whom they were anxious to deny and forget, in their haste to ape the white people.

The art of totem-pole carving now wholly belongs to the past. As it is not really ancient, it has covered altogether less than a hundred years, mostly from 1840 to 1880. For the Haida and the Niskae it came to an end soon after 1880. Elsewhere it actively survived until after 1900. The Gitksan near Hazelton have erected a few poor specimens in the past 10 years.

The age of totem poles.—It is a mistake to say that totem poles are hundreds of years old. They could not be. A green tree, cut down, carved, and planted without preservative could not stand very long, as it is highly perishable. It rots at the base, and its weight, together with the force of the wind, brings it down within a fairly definite span of years—often less than 50 years on the coast, where the moisture is intense and the muskeg foundation is corrosive. Up the rivers, where the climate is drier and the soil is sandy, some of the poles, the oldest, have stood as long as 70 or perhaps 80 years. They are among the most archaic specimens of the kind. A minute examination of each one of them on the upper Skeena has made it clear that the art of totem-pole carving there evolved out of humble beginnings mostly after 1840. In a short period of intensive development it passed through two or three phases or styles. Those of the Kwakiutl of Alert Bay, well known though they are, were erected about 1895 or later.

The growth of the system of native heraldry.—The growth of heraldry on the North Pacific coast coincides with that of the art which served it as a vehicle. On the whole it can hardly be said to be very ancient or prehistoric.

Archeologists so far have failed to unearth anything like the present totems, even in miniature form. The small stone or bone carvings and rock engravings that have been found in many places, when they are old, are of a different type—rather formless and naturistic. They have very little in common with the highly stylized art of such tribes as the Haida, the Tsimsyan, and the Tlingit.

The generation of woodcarvers that worked from 1860 to 1880 is acknowledged by the natives as the best. The names of the craftsmen have been partly compiled, details on their lives have been recorded in recent years, and their work often can be identified. They belonged in majority to the Niskæ, the Haida, and the southern Tlingit tribes.

The best-known carver of the Haida of Queen Charlotte Islands was Edenshaw. This name is hereditary, as are the personal names among the natives. Out of three generations of Edenshaws, who were reputed craftsmen, the second, from 1840 to 1880, was a reputed totem-pole carver and canoe maker. The earliest of the three was an expert metal worker or large copper-shield maker, evidently some time after the introduction of metals by European sea traders; and the third, Charles Edenshaw, who died a very old man in 1924, was the finest craftsman of the three, and the beauty of his argillite carvings and of his silver work was seldom surpassed. With him and a few of his contemporaries, native art reached the peak of its excellence. In other words, its progress was contemporary with impressionism, and even with the work of Gauguin and Van Gogh, in France.

Some of the older tribes of the Tsimsyan still remember a time when their ancestors were not totemistic, had few, if any, emblems, and did not observe the rule of exogamic marriage, which is the outstanding feature of totemic organization. Yet the Tsimsyan are now one of the only three totemistic nations of the coast.

If this type of social organization and its counterpart in heraldry existed at all before the coming of the Russians, at the end of the seventeenth century, no evidence can be found to prove it, whereas every indication points to its spread and rapid development since.

Nearly all the early mariners and discoverers, from 1775 to 1800, failed to observe real detached totem poles among the Haida, the Tsimsyan, or the Tlingit.

Some of them, like Jacinto Caamano [2] in 1792, had ample opportunities to visit Haida villages; yet, after minutely describing canoes, costumes, songs, dances, masks, and headdresses in his journal, and having stopped at Kyusta (opposite North or Langara Island) where many totem poles stood in the 1880's, he described native houses (pp. 221, 293) without a mention of totem or carved poles. That is, with the single exception of what must have been a carved house-front entrance (p. 289): "To pass through the narrow doorway of the chief's house, over which was painted a huge mask, it was necessary to make a litter or hammock of the deerskin. Two of the strongest of the Indians did this, with the other four assisting as best they could, while I was shrinking myself into as small compass as possible * * * to avoid being bumped against the door posts."

Only a very few house posts and portals, roughly carved, crude masks and carved objects were seen in some places and in house-front

[2] The Journal of Don Jacinto Caamano, translated by Capt. Harold Grenfell, R. N., edited with an introduction and notes by Henry R. Wagner and W. A. Newcombe. Reprints from the British Columbia Hist. Quart., July and October 1938, pp. 189–301.

paintings. Two or three drawings were made by the visitors at the time, in particular the sketch by Webber, in Captain Cook's Voyages, showing the carved posts inside a Nootka house on Vancouver Island. Haswell,[3] in 1787–1789, wrote: "* * * For ornaments they (the sides of the houses) have pillars supporting the poles carved into the shape of human faces with distorted features, beasts and imaginary animals * * *." Hoskins,[4] in 1790–1793, noted that: "their head villages are neatly and regularly built; the houses end on with pitched roofs; in front is a large post reaching above the roof, neatly carved but with the most distorted figures; at the bottom is an oval or round hole which is either the mouth or the belley of some deformed object. This serves for a doorway * * *." W. A. Newcombe[5] states that in "a Quimper Manuscript" (re house poles on Clayoquot Sound, 1790), Wicananish house is said to have had "carved house supports as well as the doorway pole * * *."

Capt. Joseph Ingraham's[6] description may imply that two totem poles, in 1790–1792, already were of the detached type, standing away from the house front. "I went to view two pillars which were situated in front of a village * * * on the north shore; they were about 40 feet in height, carved in a very curious manner, indeed representing Men, Toads, etc., the whole of which I tho't did great credit to the natural genius of these people. In one of the houses of this village, the door was through the mouth of one of the before-mentioned images * * *" (p. 107). "* * * Before one of the Houses were 4 Images resembling the Human form and otherwise curiously carved."

From a few of those records,[7] it is clear that the typical stylization of west coast art already existed in the neighborhood of the present Alaskan frontier. But it must have been fairly restricted in scope, at the time, and also in the area of its diffusion. Was this stylization aboriginal or derivative? It had every chance of being derivative. Yet it is difficult to say whence it would have been derived, for the lack of sufficient comparative data. Advanced stylization can be the result only of intense cultural development, such as never had happened on the North Pacific coast in prehistoric times.

From distant resemblances, it seems that some of the designs, like the culture itself, are of an Asiatic type. The use of masks is fairly modern among the northernmost nations of the coast, but it seems to have been common on Vancouver Island at the time of the discovery.

[3] Voyages round the World in *Columbia Rediviva* and sloop, 1787–1789. Transcript in the Provincial Archives, Victoria, B. C., observed by Dr. Diamond Jenness.

[4] Voyage to the Northwest Coast of America and China, 1790–1793. (He was, according to Dr. Jenness, officer on the same vessel, *Columbia Rediviva,* under Captain Gray.)

[5] Victoria, B. C.

[6] Journal of the brigantine *Hope* of Boston, 1790–1792. Stated to be in the Library of Congress, Washington, D. C. (Transcript in the Provincial Archives, Victoria, B. C.)

[7] See Voyage round the World, performed in 1785, 1786, 1787, and 1788, By Capt. Geo. Dixon; ill. facing p. 188; 1A, a carved dish, from Queen Charlotte Isles; 2A, front view.

Masks are also commonly used in Asia. The Tlingit patterns on Chilkat blankets, among other things, resemble those on the garments of the Ainus in northern Japan. The northwest coast people are not the only ones at the edge of the Pacific to have erected tall carved memorials or totems. These are also known under various forms in Japan, Korea, and in the South Seas. Some of the New Zealand carved poles so closely resemble the older poles on the Nass River, in British Columbia, that one might easily be mistaken for the other. The technique of erecting them, besides, was identical. It is quite possible that the Hawaiians and Kanakas of the South Seas, brought over to the coast of British Columbia and Alaska by the early circumnavigators, may have had something to do with the development of this local art in America, or vice versa.

Indeed, the sea hunters and seamen on board the sailing ships cruising the Pacific and following the schools of sea otters and hair seals in their migrations around the Pacific—from the northwest coast to South America and to the South Seas—consisted largely of Haida, of Coast Tsimsyan, and of Hawaiians; and this for many years. In the course of this prolonged intercourse, cultural exchanges must have taken place. Many Kanakas settled and intermarried among the natives on the North Pacific coast. Indian families at widely scattered points—on the Nass, on the lower Skeena, among the Kwakiutl and on Burrard inlet near Vancouver—now claim a Kanaka for an ancestor. For instance, Oyai, the best carver of totem poles on the Nass, is said to have been partly of Kanaka extraction; as was also the noted Kamano family of Alert Bay, among the Kwakiutl. Charles Edenshaw, Massett, was fond of representing his canoemen with curly hair (like the Kanaka's), in his argillite carvings. The Kanakas, from the earliest days of circumnavigation almost to the present time, were numerous on the North Pacific coast. Not a few wood carvings found on the coast of British Columbia and Alaska undoubtedly were from the hands of South Sea islanders. And it is possible that South Sea carvings may be from the hands of Haidas, as it is still remembered on the Queen Charlotte Islands that at least a shipload of Haidas, once not so long ago, started on a long hunting cruise across the Pacific and never came back. The Haidas themselves picked up, in the tropical seas, the abalone shells, which were extensively used in the decoration of their wood carvings and ceremonial blankets; these shells were also used in the same way by the South Sea Islanders. A further study of exchanges between northwest coast Indians and the Polynesians, from the end of the eighteenth to the end of the nineteenth centuries, would disclose that obvious cultural resemblances among them are recent and due to the stimulus of incessant contacts and mutual inspiration.

Where the detached totem poles first appeared.—It is possible that the custom of erecting detached poles as memorial columns to the dead originated among the Tsimsyan of the lower Nass River, close to the present Alaskan frontier on the coast. Or perhaps among the Haida. But if it were more ancient there than elsewhere, it does not date back very far. The old people have heard of the time when two out of three of the Tsimsyan nations had no totem poles. One of those nations along the coast in fact never quite adopted that custom, as it passed under the banner of Christianity about 1850, a decade or so before totem poles became the fashion in the north.

It is more likely that the Tlingit in this respect imitated the Nass River people or the Haida than the reverse. Candlefish or ulaken fishing made of the estuary of the Nass the most important thoroughfare of native life in the north. Ulaken was a universal and indispensable staple. Tribes of several nations gathered every spring for the ulaken run in the neighborhood of the present Fishery Bay. During several weeks, exchanges of all kinds, barter, social contacts, and quarrels were normal. Cultural features of the Nass as a result were observed by the strangers and imitated, the technique of weaving ceremonial blankets later known as Chilkat blankets,[8] and wood carving, in particular. The Nass River carvers are known to this day to have been about the best in that whole country, and their totem poles were the finest seen anywhere. The 20 that stood there until recently were on the whole the tallest and the best on the seacoast. They were also among the oldest.

[8] The Nass River people claim to have been the earliest to weave this type of blanket; and it is stated, in Alaska, that the Chilkat (Tlingit) tribe merely "cashed in on it" at a later date. The author, several years ago, collected one of the old Niskæ blankets at Gitlarhdamks; and this specimen, with designs at variance with those of the later Chilkats, is now at the Royal Ontario Museum, Toronto.



1.



2.



3.

1. The Eagle's Nest pole, 66 feet high, at Gitiks, near the mouth of the Nass River. Carved by Oyai, nearly 70 years ago. Now standing in the Zoological Garden near Quebec. 2. The leaning pole is that of Sarait'wan, so-called "Chief Mountain," at Gitiks, near the mouth of the Nass. It is 81 feet high, the tallest and largest known. Now it stands in the rotunda of the Royal Ontario Museum at Toronto. 3. The Halibut pole, belonging to a Nass River family within the Eagle phratry, at Gitiks, on the lower Nass.



1.



2.



3.

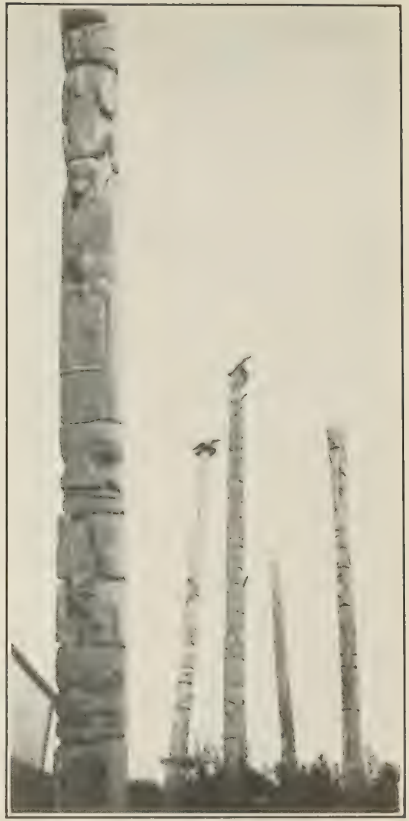
1 An old pole of the Angyadae village, on the lower Nass, belonging to a clan within the Raven phratry. Now at the Royal Scottish Museum at Edinburgh. 2. The Niskiwaetk pole at Angyadae, on the lower Nass River. It belonged to the family of Niskiwaetk within a Wolf clan; their main emblem being the Grizzly Bear. Now at the Trocadero Museum in Paris. 3. Part of the Crane and Grizzly Bear pole—an old and tall one—at Angyadae, on the lower Nass. It belonged to a clan within the Wolf phratry. Now in the Royal Ontario Museum, Toronto.



1.



2.



3.

1. A Grizzly Bear and Wolf pole, about 35 feet high and about 50 years old, at Angyadae, on the lower Nass. 2. A totem pole cluster at Gitwinlkul, a Gitksan village near a lake midway between the Nass and Skeena Rivers. 3. The northern end of the row of totem poles at Gitwinlkul.



1.



2.

1. Gitksan totem poles at Kitwanga, on the mid-Skeena. A few of these are among the oldest in existence. 2. Gitksan totem pole cluster at Kispayaks, on the upper Skeena.



Haida totem poles at Skidegate, Queen Charlotte Island, as they stood about 1900.

HISTORIC AMERICAN HIGHWAYS

By Albert C. Rose

Senior Highway Engineer, Public Roads Administration, Federal Works Agency

[With 18 plates]

William Shakespeare, the bard of Stratford on Avon, whose portrayal of the human character and mastery of the art of expression has delighted the lovers of the best in English literature for generations, once made the observation that:

> All the world's a stage,
> And all the men and women merely players.

The great playwright well knew the power of the drama to plumb the depths of the human emotions through the sense avenues of sight and hearing. He was adept in the use of a stage setting to portray ideas which words alone never could express.

To this day these pictorial tools give a dramatist a decided advantage over the writer who strives bit by bit to build up a word picture in the mind of the reader with the aid of a pen or pencil alone. The author accomplishes his purposes progressively by means of skillfully associated words, phrases, sentences, and paragraphs in which the original thought germ grows until it is revealed full-fledged in its final form. This mental scene which the writer builds gradually the artist presents instantly by means of a picture blurred by no barrier of language, latitude, period, or age. Thus the Eskimo in Greenland and the Hottentot of South Africa may be instructed to see the same physical elements in a picture even though their emotional reactions to the sight may be strangely different. The ancient Chinese no doubt had these ideas in mind when they formulated many centuries ago their celebrated proverb: "Hua-i neng ta ch'ien yen." This old saying, according to Dr. A. W. Hummel, Chief of the Division of Orientalia of the Library of Congress, means literally, "Picture's meaning can express a thousand words," or a more familiar translation is, "One picture tells a thousand words."

It is because pictures express ideas in the clearest and most summary form that this effort has been made to present the story of American highways with the aid of a series of dioramas—a technical term used

by artists to signify a scenic background combined with a modeled foreground. The thread of the historical narrative may be traced through the following text wherein the plate numbers in parentheses refer to the pictures of the dioramas arranged in chronological order at the conclusion of this article.

This series of 35 historical dioramas, arranged to be viewed progressively with the aid of an elaborate mechanism combined with mirrors, and described by a well-modulated sound record, was displayed first at the Golden Gate Exposition in San Francisco, Calif., in 1939. In the same year a three-color motion picture of the dioramas was shown at the New York World's Fair.

THE HISTORICAL NARRATIVE ILLUSTRATED BY THE DIORAMAS

The story of the development of transportation in Colonial America and the United States during the past four centuries is a moving word picture which flashes upon our mental screens successive images illustrative of our thoroughfares as they grew from the status of primitive wild-animal and Indian trails into the present high-speed highways suitable for motor vehicles. This historical narrative covers a period during which European civilization marched westward from the Atlantic coast line to the shores of the Pacific Ocean and along the way overcame mountain, desert, and forest barriers. In the wake of this extensive and intensive pioneer movement there arose great industrial cities to supplant the earlier scattered log-cabin settlements.

The story begins with North America in the condition of a vast wilderness inhabited only by the Indian aborigines, animals, birds, and fishes. Spain was the towering world power of the time, and her explorers were seeking to extend the empire to the ends of the earth. Christopher Columbus had sailed a due west course toward the fabulous wealth of the Indies and had stumbled upon an unknown land which later became known as America.

Throughout this so-called New World the horse species had been extinct since prehistoric times. Only fossil remains bore witness to their previous existence. The cause for the disappearance of the equestrian animals defies identification and may remain always a mystery. However, a number of hypotheses have been advanced. Perhaps there occurred some sudden change in climate such as a prolonged drought. The lives of the new-born foals might have been destroyed by vicious insect pests. The steady pressure of the increasing population of other animal species may have made life less tenable. Death from widespread disease is another theory that has been suggested. Whatever may be the true inwardness of the nature of the cause which brought about the disappearance of the

genus *Equus*, historians are agreed that the Spaniards introduced the forefathers of the modern horse into the New World. The Spanish conquistador Hernando de Soto (pl. 1, fig. 1) probably transported across the Atlantic Ocean the first horses which survived to renew the species on the soil now occupied by the United States. His fleet of caravels entered a sheltered body of water which De Soto named "Espiritu Santo" (Holy Ghost) and which we call today Tampa Bay. Probably on May 28, 1539, the landing of more than 200 horses was made at Gadsen's Point. Numbered among this group of magnificent Arabian horses was De Soto's favorite mount Aceituno, from a strain of great longevity, productiveness, and hardihood and like the evergreen olive tree the symbol of wisdom, peace, and majesty.

Many years elapsed, however, before horses were used for travel and transportation by the American Indians. When the English established their first permanent settlement at Jamestown, Va., in the year 1607, the Atlantic Ocean and its tributary streams supplied the main highways to and into the newly discovered continent. In the region where the birch tree grew to suitable proportions, and on rough bodies of water, the birchbark canoe was the favorite vehicle. In the locality where the surface of the streams and bays remained relatively placid the southern Indians used dugout canoes made by building a fire upon a sound log and scraping away the charred remains with a clam shell or other rude instrument (pl. 1, fig. 2). When Captain John Smith met the great chief Powhatan at his principal Indian village 1 mile downstream from the present site of Richmond, Va., on the James River, his daughter Pocahontas used a log bridge to cross a stream. The dusky forest denizens roamed the forests on foot, resorted to hand litters to move the sick, and transported heavy burdens on their backs.

When another 70 years had elapsed, the land of America remained still an unknown wilderness in which distances were traversed only with extreme hardship. At the risk of their lives Old World explorers continued to seek a direct route overland toward China and Japan by paddling their canoes up the rivers and portaging or carrying their equipment and supplies across the land divides separating the main water courses. On January 22, 1679, Robert Cavalier, Sieur de La Salle, the celebrated French explorer (pl. 2, fig. 1), in search of a short-cut to the Far East, stood on the portage path around Niagara Falls in company with his bosom companion, the Franciscan Father Zénobe Membré. La Salle's enthusiasm might have been dampened had he the foreknowledge that the venture would cost him his life. Undaunted by anticipated danger, however, his forceful character won the confidence of his followers. At his

command the baggage of the expedition and the canoes were carried across the portage path on the backs of the common laborers or engagés. The packs were balanced by tumplines encircling the foreheads of the burden bearers.

While the French in the north and the Spaniards in the southwest were extending their dominions in North America, the English were establishing lucrative possessions along the Atlantic seaboard. Throughout the southern group of Colonies the plantation system retarded road development. The extensive acreages of privately owned farms bordered upon navigable streams, on the banks of which were private docks where the products of the soil were loaded on board ocean-going ships. Tobacco was the money crop of the Virginia planters, and hogsheads filled with the precious weed were rolled (pl. 2, fig. 2) from field warehouses over tobacco-rolling roads to the river landings for shipment to the English mother country far across the sea. A rope attached to the hogshead and held in the hands of a Negro was used as a brake to prevent the hogshead from overrunning the oxen when traveling downhill.

Toward the close of the eighteenth century road improvement in the northern colonies was undertaken by the township authorities. This work speeded the Colonial mail service which had been established in North America first, in 1673, on the famous Boston Post Road leading from New England to New York. In less than a century the postal system had become so extensive that Colonial Postmaster Benjamin Franklin (pl. 3, fig. 1), in 1763, seated in a well-kept one-horse shay and accompanied by his daughter on horseback, made a long inspection tour of the Colonial post offices. While he was journeying over the Boston Post Road, a tireless post rider delivered an urgent message to his chief.

The growth of the mail service in the eighteenth century was the natural accompaniment of a corresponding increase in the volume of business carried on between the Colonies. Although the bulk of the passenger and freight movement was cared for in coastwise vessels, attempts to improve land transportation began at an early date. The first venture in rapid transportation was made, in 1766, by the crude box-shaped covered wagon called the Flying Machine (pl. 3, fig. 2), on the road between the cities of Philadelphia and New York. This lumbering vehicle, with springs only under the crosswise board seats, covered in 2 days the 90-mile distance between the Quaker City and the Paulus Hook Ferry, now known as Jersey City. The two trips a week were multiplied into daily runs by 1773.

For the century and a half and more outlined in the preceding paragraphs the British settlements in North America had been confined to a narrow strip of land, 150 miles wide, sprawled along the

Atlantic seaboard. The general movement of travel was in a north-and-south direction. Then, just before the Revolutionary War when there was widespread unrest because of the congestion of population and the burden of illegal taxes, the courageous pioneer Daniel Boone began the westward emigration into the unknown country beyond the Allegheny Mountains. He led his followers through the Cumberland Gap (pl. 4, fig. 1) and over the blazed trail now known as Boone's Wilderness Road.

Prior to the War of the American Revolution travel throughout the Colonies was accomplished principally on foot or horseback, and the average rate of travel did not exceed 4 miles an hour. Improvement in the means and methods of transportation was retarded by the chaotic social and economic conditions which were a natural aftermath of the war. It was not until 1795 that organized road improvement may be said to have begun. In that year a privately owned turnpike company finished the first extensive broken-stone roadway in this country. This was the 62¼-mile Lancaster Turnpike leading westward from Philadelphia (pl. 4, fig. 2). Weary and hungry travelers were entertained by the hospitable host at the Eagle Tavern standing beside the road about 14 miles from the City of Brotherly Love. The improved stage wagons in use at this time, averaging 5 to 7 miles an hour, represented the next step in the development of this type of vehicle from the primitive covered box wagon to the later Concord coach.

With the Lancaster Pike as a beginning, stone-surfaced roads grew in number and extent east of the Appalachian Mountains. It was not until work was started on the National Pike, in 1806, that the western transmountain settlers were given hope of relief from their isolation. The new States of Kentucky and Tennessee, with their commercial connection with the East restricted to the long rough wagon road through the wilderness across the Appalachian divide, sought a southwestern water outlet by way of the Mississippi River. Flatboatmen who made the successful journey downstream sold their products at New Orleans and returned home by the short cut through the woods beginning at Natchez, the farthest southern town on the hard ground bordering the swampy region below. Travel over this forest path grew to such proportions that shortly before the Louisiana Purchase was consummated, in 1803, the Congress of the United States ordered the formal opening of this so-called Natchez Trace leading northeasterly to Nashville, in Tennessee, for a distance of less than 500 miles. On this beaten path or trace, through the leaf-mold in the woods, Gov. Meriwether Lewis of Louisiana Territory lost his life on the night of October 11, 1809, at Griner's Tavern (pl. 5, fig. 1) situated in Tennessee about 72 miles south of Nashville.

This celebrated partner of the Lewis and Clark expedition into the Pacific Northwest was on his way to the National Capital at Washington to make a report to President Thomas Jefferson.

The subsequent improvement of the Natchez Trace was hastened to some extent by the Napoleonic Wars which raged in Europe and which were responsible indirectly for our War of 1812 with England. Gen. Andrew Jackson moved American troops southwest over the Natchez Trace for the defense of New Orleans. The decisive operations of the struggle, however, consisted of naval engagements, and the British blockade bottled our coastwise sailing packets in the American harbors. These operations were so successful along the Atlantic seaboard that the freight business between New England and the southern States had to be transferred to Conestoga wagons. This abrupt increase in coastwise land travel soon overtaxed our infant highway system. An example of this was to be seen at Trenton, N. J. (pl. 5, fig. 2), where the heavy freight wagons, carts, and stagecoaches rumbled beneath the elaborate facade of the Delaware River bridge.

With the signing of the treaty at Ghent, in December 1814, which concluded the War of 1812, there began a century that was to be characterized by revolutionary improvements in transportation and communication. This was a logical corollary to the growth of the new factory system. An expanding market for the industrial civilization in the East was provided by the emigrants to the new lands in the West which were being opened for settlement and trade. The first of the great overland roads to the Far West was the Santa Fé Trail which connected the western frontier of the United States at Independence, Mo., with Mexico. At the starting point on the American frontier the traders unloaded their covered wagons and supplies from steamboats plying on the waters of the Missouri River (pl. 6, fig. 1). The steel tires were tightened on the wagons to prevent their shackling, or loosening and rattling, when the wooden wheels shrank on the long journey across the deserts parched dry by the burning sun.

Soon the struggle to improve the methods of transportation became more intense, and well-built canals challenged the supremacy of the horseways in the East. To tap the vast region surrounding the Great Lakes the Erie Canal was opened to travel in 1825 (pl. 6, fig. 2). This new waterway provided almost a level connection across the barrier of the Appalachian Mountains. New York City, at the mouth of the Hudson River, became the nearest Atlantic seaport for the new States carved from the Northwest Territory. Philadelphia had been displaced previously as the leading metropolis of the country.

As settlers began to stream into the Great Lakes region by way of the Erie Canal there arose a need for a more direct route for emigrants from the East and South. An overland connection was established across the narrow land bridge of Indiana which separated Lake Michigan from the Ohio River valley. This route, called the Michigan Road, after the name of the lake, was laid out along the shortest practical route between the two water thoroughfares. The location of the northern leg of this road had been established unwittingly by the French Canadian Pierre Frieschutz Navarre, when, as an agent of the American Fur Co., he built his trading cabin on the east bank of the St. Joseph River. The native trappers transported packs of beaver pelts across the portage trail leading from the Kankakee River and then floated their wares in canoes across the St. Joseph River to Navarre's cabin (pl. 7, fig. 1). Around this location as a nucleus grew the present city of South Bend, Ind. Settlers, called "movers," left the eastern States and floated down the Ohio River to begin their northward journey into Indiana over the Michigan Road. Over the same road emigrants swarmed from the southern States of Kentucky, Virginia, and the Carolinas.

The growth of the new commonwealths in the Northwest was balanced in some degree by the new States formed in the Southwest from the territory acquired by the Louisiana Purchase. The mouth of the Mississippi River had grown in commercial importance to such an extent that by 1827 there came a demand for a great mail road, which was intended to branch from the National Pike, leading westward from Cumberland, Md. From Zanesville, Ohio, the new road was to pass through Maysville and Lexington in Kentucky, Nashville in Tennessee, to Florence in Alabama, and thence to New Orleans in Louisiana. The Maysville Pike section of this road became a national household word when Federal aid for its construction was vetoed by President Andrew Jackson on May 27, 1830. With this action as a precedent, private corporations were forced to take over the financing of the main public roads. This legislation was influential in placing the subsequent construction of the railroads in the hands of private corporations. The accompanying illustration (pl. 7, fig. 2) of a tollhouse and an oval-shaped stagecoach, typical of the period, on the Maysville Pike, shows the tollgate-keeper refusing to accept in payment some of the worthless Spanish coins in circulation at the time.

Now a mechanical rival arose to challenge the right of the horseway and the waterway to serve the growing Nation's transportation. On August 28, 1830, an open car, filled with the directors of the Baltimore & Ohio Railroad and their friends, was hitched to Peter Cooper's diminutive Tom Thumb locomotive. This new

combination lost the race to a horse-drawn railroad car on the tracks between Baltimore and Ellicott's Mills, Md. (pl. 8, fig. 1). The horse, owned by Stockton and Stokes, the great stagecoach proprietors of the day, won the race by a fluke caused by the failure of the belt that operated the blower of the engine. The race demonstrated, however, the superiority of the railway beyond the peradventure of a doubt.

While the struggle for the survival of the best kind of transportation was raging east of the Mississippi River, settlers, in 1836, were pushing their way southwestward into Texas. Slow-moving covered wagons, creaky Mexican *carreta* carts, and grunting pack animals (pl. 8, fig. 2) wound their leisurely way along El Camino Real past the Alamo, stormed shortly before by the Mexican General Santa Ana and his troops, and today the sacred shrine of Texas liberty.

For another three decades, the white canvas-topped covered wagons were relied upon as the most dependable vehicle by the emigrants to the West. In the East, however, the reaction had set in and wagons had begun to yield first place to the more efficient railroads. The recession was obvious on the National Pike, begun in 1806, to serve the territory northwest of the Ohio River and the first main highway to be built with Federal funds. By 1840, at the eastern extremity near the stone-arch bridge over Will's Creek, west of Cumberland, Md. (pl. 9, fig. 1), Conestoga freight-wagon and stagecoach owners began to feel the loss of business to the Baltimore & Ohio Railroad.

Many of the vehicles placed on the auction block by the bankrupt horse-transportation companies in the East found their way across the Mississippi River, where they were used in that extensive population movement which by the middle of the nineteenth century had pushed the frontier of the United States westward until it touched the shores of the Pacific Ocean. Beginning with a trickle of trappers to the Northwest when Astoria was founded, in 1811, the movement had swelled to a mighty stream of settlers by the time of the great emigration in 1843. The Oregon Trail, across the Rocky Mountains and down the Columbia River (pl. 9, fig. 2), joined with the extended National Pike to provide the first overland route connecting the Atlantic and the Pacific coasts.

Now that the railroads east of the Mississippi River were far in the lead of their opponents in the race to provide better transportation facilities, feeble efforts were made to better the condition of the wagon roads. It was natural that recourse should be had to wood in the region where trees were plentiful and sawmills dotted the forests. Following the example of the Canadians who built the

original plank road in North America, after the example of the Russians, the first plank road in the United States was laid, in 1846, from Syracuse, N. Y., to the foot of Oneida Lake (pl. 10, fig. 1). The road was completed in July of that year by a corporation known as The Salina & Central Square Plank Road Co.

These half-hearted improvements in the character of the horseways failed, however, to overcome the tremendous handicap which the steam railways had gained during a period of three decades. By 1850 the speed of the fastest trains averaged about 25 miles an hour, and the railroads were carrying passengers and freight over long as well as short distances. Faced with such formidable competition, the Conestoga-wagon and stagecoach companies were failing everywhere, and the highways often were becoming so rough, impassable, and muddy that a partial load could be hauled by four horses only with the greatest effort (pl. 10, fig. 2). The main highways began to fall into such a state of neglect and disrepair that this period has been dubbed the twilight of the dark ages of road travel in the United States.

Although the steam railroad dominated the whole system of transportation in the eastern States, not a single locomotive had puffed its way over a steel track as far as the Mississippi River prior to 1854. Stretching beyond the Father of Waters as far as golden California was a vast wilderness of 2,000 miles of plains, deserts, forests, and mountains which only the fastest overland stagecoach relays could span in 20 days. The need for fast mail communication between the Pacific coast and the center of government, at Washington, had been growing ever since gold had been discovered in California, in 1848, at Sutter's sawmill on the south fork of the American River near Coloma. To speed news to the new gold region a Lightning Dromedary Express (pl. 11, fig. 1) was tried first on the route between Albuquerque, N. M., and Los Angeles, Calif., in 1857, by Secretary of War Jefferson Davis. The camels were expected to travel 100 miles without water, to feed on sagebrush, and, racing across the parched desert at the rate of 10 to 15 miles an hour, to reach their Pacific destination within 2 weeks from a starting point on the Missouri River. The experiment failed partly because the easygoing but stubborn camels, lulled into obedience by the dulcet, liquid Arabic language of their drivers in Egypt and Arabia, became balky when abused in a strange land by the forceful and impetuous American mule handlers.

Undismayed by the failure of the camel express and determined to exhaust every possible means that promised to speed communication with the Pacific coast, Californians promoted another experiment in rapid mail transportation. At this time there was doubt that the

steam railroad ever would solve their problem. On April 3, 1860, west coast citizens witnessed the first fruits of their efforts when the Pony Express set out on its maiden trip. This first overland mail service between St. Joseph, Mo., and Sacramento, Calif., brought San Francisco 10 days nearer to New York (pl. 11, fig. 2). The pony rider covered about 250 miles a day of 24 hours, whereas the stagecoach traveled only 100 to 125 miles in the same time. After racing past Independence Rock, in Wyoming, for 16 months, the Pony Express was put out of business by the completion of the Pacific telegraph line. During its comparatively short life the messages carried by the daring riders on their wiry western ponies helped to preserve the Union at the outbreak of the Civil War.

With the flower of the manhood of the South and the North engaged in a titanic economic struggle, the Federal Government relaxed its vigilance with respect to the Indians in the Far West. As a result savage outbreaks began to threaten the lives and property of emigrants and settlers over a wide range of territory. These redskinned marauders, however, were placed at a decided disadvantage when the last spike was driven at the junction between the Union Pacific and Central Pacific railways, at Promontory Point, Utah, on May 10, 1869 (pl. 12, fig. 1). The new gleaming steel rails captured the business of the 8-year old stagecoach lines that had shifted, because of the War Between the States, from the southern ox-bow route to the central road between the Mississippi River, Denver, and the Pacific coast. The Concord stages were the acme of perfection reached in the manufacture of that type of vehicle. They were the equivalent of the Pullman railroad parlor cars in use today.

With the passing of the three-quarter mark of the nineteenth century, the country began to bear the earmarks of the industrial revolution brought about by the introduction of steam, machinery, and electricity. The old-fashioned handicraft work in the home was on the way out. The factory system now attracted large numbers of workers to industrial centers, where the raw materials were brought to be processed by machines driven from central power plants. There was a steady emigration of workers from the rural districts, and farm work lost much of its appeal to the younger generation now come to manhood. The country roads were now in a most wretched state. Four million devotees of the "safety" bicycle often in the nineties found crossroads signs puzzling, maps unintelligible, and the farmers indifferent to their plight (pl. 12, fig. 2).

The cyclists, organized into a League of American Wheelmen, made vociferous demands for improved roads and bicycle paths radiating from the towns and cities. The Good Roads Movement which they

initiated soon was given a tremendous impetus by the new horseless carriages which Charles E. Duryea introduced in Springfield, Mass., in 1892, and Elwood Haynes drove through the streets of Kokomo, Ind., in 1894. By the dawn of the twentieth century the new road machines had been so improved as to warrant acceptance as the first successful mechanically driven vehicles ever to be used on the wagon roads. For the first time in all recorded history the problem of mechanical transportation had been solved. There was introduced now a radical change in the method of highway transportation. Much experimentation was needed, however, before the new machines were to be made foolproof and capable of traveling over long distances without danger of a break-down. Propelled by the newly discovered internal combustion engines, the pioneer "benzine buggies," or "horseless carriages," had many a mechanical defect to tax the patience and ingenuity of their drivers and make them the laughingstock of the countryside (pl. 13, fig. 1).

Used first to transport passengers from place to place, the motor vehicle soon became recognized as a practical means for transporting freight. Motortrucks began to make their appearance first on the city streets and later on the rural roads. In 1911 the first transcontinental motor-vehicle tour was made by a Sauer motortruck, called the Pioneer Freighter, which weighed 7 tons loaded. This primitive gasoline-engine-driven truck covered the 1,500-mile distance from Denver, Colo., to Los Angeles, Calif., in 66 days. The four-man crew reported there was a great need for road improvement in the Southwest. The diorama illustrates an actual scene on the way through New Mexico (pl. 13, fig. 2) where the road was cleared of obstructions with the aid of shovels and crowbars.

As the output of the automobile plants was increased steadily by improved methods of mass production, the average daily journey of all motor vehicles was lengthened far beyond the 20-mile limit customary in the heyday of the horse and wagon. Good roads, fostered by State-aid road laws since the advent of the bicycle, had crossed the boundaries of counties and, by 1916, had reached the borders of some States. At the State line travelers often found their progress halted by a muddy, neglected section of road, which was the product of the lack of initiative on the part of the adjoining State (pl. 14, fig. 1). To bridge these gaps and promote the continuous improvement of an interstate system of through roads the Congress of the United States passed the Federal-Aid Road Act on July 11, 1916.

For some years the fast-multiplying heavy loads on solid-rubber motortruck tires had created problems never raised before by wagon loads on tires made of steel. The suction of the rubber tires disintegrated the water-bound stone surfaces and caused them to be

dissipated in clouds of dust. Also the impact of the heavy concentrated wheel loads of the motortrucks exceeded the powers of resistance of the old-style wagon road. Modifications were needed in both the old road surface and the new motor vehicle. To discover a rational solution to these problems the first large-scale highway research was begun, in 1920, in Federal laboratories at Arlington, Va., and on experimental roads at Bates, Ill., and Pittsburg, Calif. (pl. 14, fig. 2). These tests were instrumental in bringing about the adoption of pneumatic balloon tires and the thickened-edge design of pavements.

Faced now with the popular desire for travel on rubber, road-building agencies were converting as rapidly as possible the early disconnected roads of each State into continuous long-distance routes. In the neighborhood of towns motorists were able to find their way in spite of the crude direction signs. When a long journey was ventured, however, the highway traveler was confused by the motley array of informational signs erected independently in each State. To bring order out of chaos and thus speed the tourist on his way uniform numbered United States shields, and warning, danger, and informational signs were adopted, in 1925, for Nation-wide use by the Joint Board on Interstate Highways appointed by the Secretary of Agriculture. Soon maintenance crews were at work dismantling the old markers and erecting new ones (pl. 15, fig. 1).

The volume of road construction spurred on by the growing number of motor-vehicle registrations had grown steadily over a long period of years when a sharp increase in Federal road-building activities was authorized as an antidote to the protracted business depression following the financial crash of 1929. All road improvement was quickened, in 1933, by large appropriations made by Congress to provide work for the unemployed. Speeding work on the main highways and city streets, the Federal Government also for the first time extended Federal aid to the improvement of the farm-to-market roads (pl. 15, fig. 2).

To provide further gainful employment special Federal funds were appropriated to make railroad grade crossings safer (pl. 16, fig. 1). The need for this work was emphasized by the mounting heavy toll of traffic accidents. The thousands of bridges that have been built each year, since 1934, with these funds will safeguard many lives and limbs and also save motorists annoying stops while waiting for passing trains.

In cities, too, the new Federal funds for the elimination of hazards at railroad grade crossings made possible the construction of long viaducts. These structures, as early as 1935, began to do away with many dangerous crossings. Furthermore, these viaducts put a stop

to the congestion of traffic at level crossings where long queues of motorists used to be blocked while waiting for an opening through lines of shifting freight trains (pl. 16, fig. 2).

The fruits of comparatively small expenditures for roadside improvement became noticeable even before 1937. Encouraged by the Federal Government this landscaping and planting work is restoring rapidly the natural beauty of American roadsides. Gently rolling, grass-covered side slopes are built to replace water-worn steep embankments. This skillful treatment pleases the eye and pays extra dividends in added safety and the prevention of soil-destroying erosion (pl. 17, fig. 1).

A prediction concerning future trends and innovations in road building can be ventured only with the utmost caution. The long-distance view beggars the imagination. In the immediate future, however, it seems certain that there will be continued the present efforts to speed the free flow of traffic. Many express highways soon will conduct entering traffic safely and quickly to the hearts of the big cities. Alternate belt-line routes will speed travel around metropolitan areas within the suburbs. Complete separation of opposing and intersecting traffic streams and the construction of pedestrian and bicycle paths, as illustrated in plate 17, figure 2, will make future main highways ideally safe and efficient.

In proof that these future predictions have a solid foundation there is presented an engineering masterpiece of the twentieth century—the San Francisco-Oakland Bay Bridge (pl. 18). As a dramatic conclusion to this pictorial history of the highways of America this product of the young and vigorous West symbolizes in all its strength and beauty and by its self-evident usefulness—the highways of tomorrow!



1. 1539. THE COMING OF THE HORSE.



2. 1607. THE INDIAN CANOE.



1. 1679. THE PORTAGE PATH.



2. 1760. THE TOBACCO-ROLLING ROAD.



1. 1763. THE BOSTON POST ROAD.



2. 1766. THE FLYING MACHINE.



1. 1774. THE WILDERNESS ROAD.



2. 1795. THE LANCASTER PIKE.



1. 1809. THE NATCHEZ TRACE.



2. 1814. GROWTH OF COASTWISE TRAVEL.



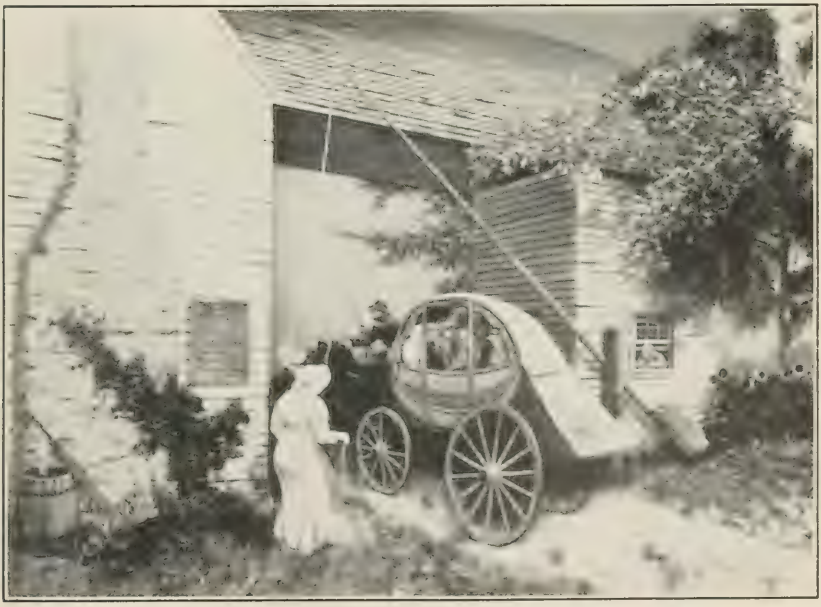
1. 1822. THE SANTA FÉ TRAIL.



2. 1825. THE ERIE CANAL.



1. 1826. THE MICHIGAN ROAD.



2. 1830. THE MAYSVILLE TURNPIKE.



1. 1830. THE IRON HORSE.



2. 1836. EL CAMINO REAL.



1. 1840. THE NATIONAL PIKE.



2. 1843. THE OREGON TRAIL.



1. 1846. THE PLANK ROAD CRAZE.



2. 1850. DARK AGE OF THE ROAD.



1. 1857. THE CAMEL EXPRESS.



2. 1860. THE PONY EXPRESS.



1. 1869. THE MEETING OF THE RAILS.



2. 1892. BICYCLING DAYS.



1. 1900. THE HORSELESS CARRIAGE.



2. 1911. THE MOTOR PATH FINDERS



1. 1916. MUD AT THE STATE LINE.



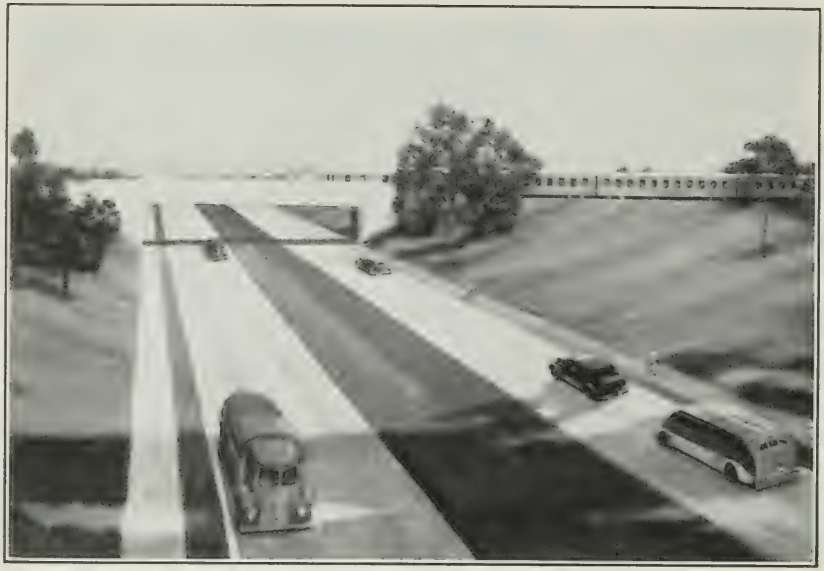
2. 1920. BEGINNINGS OF HIGHWAY RESEARCH.



1. 1925. ADOPTION OF UNIFORM SIGNS



2. 1933. ROADS TO SERVE THE LAND.



1. 1934. RAILROAD CROSSINGS BRIDGED.



2. 1935. VIADUCTS IN CITIES.



1. 1937. ROADSIDE BEAUTY RESTORED.



2. 1938. CITY ENTRANCES AND BELT LINES.



1939. A HIGHWAY MASTERPIECE.

MODERN TRENDS IN AIR TRANSPORT[1]

By W. F. Durand

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In a domain as varied and as active as is air transport at the present time, I can only hope, in the time which I must occupy this afternoon, to touch on some of the more important phases of the subject. And first, by way of introduction, I should like to rehearse with you a few simple and elementary points regarding the airplane—a body heavier than the air, yet which, for service in air transport, must depend on sustained movement through the air.

Let us then picture the airplane as a complex of four systems as follows:

1. The lifting system.
2. The nonlifting system.
3. The propulsive system.
4. The control system.

The lifting system is, of course, represented by the wings. The nonlifting system is represented by the body or fuselage, the purpose of which is to provide a central structural member, with space for personnel and pay load, to provide suitable support and location for the rudder and elevator as parts of the control system, and often to house, at the nose, an engine and propeller shaft. The propulsive system comprises the engines and propellers with function as indicated by the name. The control system comprises rudders, elevators, ailerons, flaps, slots, etc., all intended to place in the hands of the pilot control over the movement of the plane in the air and also in taking off from the ground and returning thereto.

Now, what are the things about an airplane and its performance in which we have a special interest? I shall put them down in this order:

1. Safety.
2. Carrying capacity.
3. Speed.
4. Range.
5. Economy.
6. Comfort.

[1] Address given at the 39th annual convention of Sigma Xi at Richmond, Va., December 28, 1938. Reprinted, with author's revisions, by permission from Sigma Xi Quarterly, vol. 27, No. 1, March 1939.

This may or may not be the order of relative importance, according to the viewpoint from which "importance" is judged. Thus the order of importance for planes in commercial service and in military or naval service would not, in general, be the same. It will, moreover, be convenient to discuss the present trend with regard to these various characteristics in a somewhat different order, and I shall take first No. 2, carrying capacity.

The laws of fluid mechanics tell us immediately that the lift of an airplane wing increases directly with the area, with the square of the speed, and, over most of the practical working range, with the angle of attack of the air on the face of the wing. This angle may be represented by the angle between the direction of motion of the plane and a fore and aft line touching the under face of the wing. It represents what may be called the attitude of the wing relative to its direction of motion.

It would appear then, that in order to increase the lift of an airplane wing, we have only to select some combination of larger area, higher speed, and greater angle of attack. It is not, however, quite so simple. What we are ultimately concerned with is not so much the gross lift of the plane as the useful part of this lift—that is, the balance of the total lift over and above what is necessary to sustain the weight of the plane as a whole, including engines and propellers. In thus approaching the economics of airplane operation, we recognize three subdivisions of the total lift:

1. The weight of the plane, including power plant (engines and propellers).
2. The useful load subdivided into—
 a. Fuel and oil, operating personnel, supplies.
 b. Pay load—passengers, mail, express matter, etc.

Again, the weight of the plane together with its power plant may be viewed as a dead load which must be sustained in the air simply in order to realize the purposes of flight; whereas the useful load represents the part of the total lift disposable as may be desired, between fuel, supplies, and personnel on the one hand, and pay load on the other. Thus with a small fuel load, a relatively large pay load may be carried for a short distance; with a large fuel load, a relatively small pay load may be carried for a long distance.

Now to return to the results following an increase in wing area, or, in general, an increase in the size of the plane. As we have seen, other things being equal, the lift will increase with the area. But the weight of the structure will increase likewise, and the results on the useful load are, therefore, by no means assured. In order to follow this point more closely, we must now discriminate between the weight of the plane simply as a structure and the weight of the power plant which it carries. I have referred to the sum of these two weights as

the weight of the plane in contradistinction to the amount of useful load which it can carry. We may now refer to the aggregate weight of the structural elements of the plane simply as the weight of the structure. With these conventions, then, weight of plane equals weight of structure plus weight of power plant, and the total lift must equal weight of the structure, plus weight of power plant, plus the useful load.

Let us now turn to the relation between weight of structure and wing area. We have seen that gross lift, other things being equal, will increase with the area—that is, with the square of a linear dimension. Now it is an inescapable consequence of the laws of structural mechanics that, for wing structures carrying the same load per unit of area and with the same geometry of design and materials of construction, the dimensions of all structural elements must vary in the same ratio as that for the over-all dimensions. This means, for example, that if the over-all dimensions were increased twofold, the wing area would be increased fourfold, whereas the volume and hence the weight of all structural elements would be increased eightfold. This is often referred to as the square-cube law, implying, as it does, that with increase in over-all dimension, the lift will increase with the square of the linear dimension and the weight of the structure with the cube. According to this law, then, with increase in size, the weight will increase at a much faster rate than the lift, and, unless some escape is found, this excess weight would soon absorb the difference between the total lift and the weight of the plane and thus reduce the useful load to zero. The law is inexorable under the conditions stated, and in the early years of airplane development, led to prophecies of sharp limitation in the increase in size of airplane structures. The ways and means whereby the consequences of this law have been evaded form one of the most brilliant achievements in the development of airplane design and construction. I must take only the time to indicate them in briefest outline. They comprise, first, more efficient methods of design whereby the material employed is more effectively distributed with reference to the loads to be carried; second, improved materials of construction; third, improved aerodynamic design whereby for the same power, increased speed may be obtained, and with increased speed, increased lift with the same wing area.

There is a further factor which helps in the same direction. The structure of the plane, under certain conditions, as we have seen, would be subject to this square-cube law. The power plant would not be so subject. Power is related primarily to surface or, broadly, to wing area. For the same speed, therefore, the power required will increase with the wing area, or as the square of the linear dimension rather than as the cube. One part of the weight of the

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plane is, therefore, not subject to this law, even under the conditions where the weight of the structure would be. This helps to reduce the rate of increase of weight of plane with increase in size.

Another factor in increase of lift is higher speed, and this has been used with telling effect since lift increases as the square of the speed. However, increased speed means larger engines and more weight of power plant, as well as more lift per unit of area and, therefore, more loading per square foot of wing area. The law of compensation holds here; if we would obtain more lift we must buy it at a price.

A third factor in increase of lift is increased angle of attack between the air and the wing. This is indeed effective, but it demands too heavy a price. With the increase of lift comes also an increase of drag or resistance to the motion of the plane. This means more engine and more power plant weight for the same speed, or a reduced speed for the same power plant weight. The price is too high and can only be afforded during periods of maneuver at low speed, as in taking off from the ground, or landing thereon, where the decrease in lift due to decreased speed is compensated by the increase due to greater angle of attack.

Other contributing causes have helped along in the same direction of evading the consequences of this square-cube law, and it would be a brave man who would now attempt to place a limit to future increase in size.

Twenty years ago, during the Great War, there was no commercial aviation. The total lift, that is, the total loaded weight of military planes was, for the most part, from 3,000 to 5,000 pounds. The earliest commercial transport planes had a total loaded weight from 5,000 to 10,000 pounds. The planes in current transport service weigh loaded 20,000 to 40,000 pounds; the China Clipper has a loaded weight of 52,000 pounds. The new Boeing flying boat will weigh loaded 82,000 pounds, the new Douglas 4, which has been undergoing test flights, will have a loaded weight of 65,000 pounds. Beyond these figures, new designs have been submitted by four builders for trans-Atlantic service, the loaded weight of which will be about 200,000 pounds.

Some further particulars of these latest planes may be of interest. The present standard Douglas 3, of 24,000 total lift, has a wing spread of 95 feet, a wing area of 985 square feet, a wing loading of 24.3—that is, each square foot of wing area supports in flight 24.3 pounds. It has engines developing 2,000 horsepower, a cruising speed of 170 miles per hour, a range of 500 miles with a pay load of 5,200 pounds including 21 passengers. Corresponding figures for the present China Clippers are: weight 52,000, wing spread 130 feet,

wing area 2,320 square feet, wing loading 22.5, power, 4 engines developing 3,600 horsepower, cruising speed 130 miles per hour, range 2,400 miles, and pay load 2,600 pounds including 8 passengers. The new Douglas 4 of 65,000 pounds has wing area 2,130, wing spread 138 feet, wing loading 30.5, power, 4 engines developing 5,600 horsepower, cruising speed 170 miles per hour, range 1,000 miles with a pay load of 9,400 pounds including 40 passengers. The new Boeing flying boat, with a total lift of 82,500 pounds, has a wing area 2,880 square feet, wing spread 152 feet, wing loading 28.8 pounds, 4 engines developing 5,950 horsepower, cruising speed 150 miles per hour, range 2,400 miles with a pay load of 10,000 pounds including 40 passengers.

The recent Boeing 307, intended especially for stratosphere flight, with a total lift of 42,000 pounds, has a wing area of 1,390 square feet, a wing spread of 107 feet, wing loading 30.3 pounds, 4 engines developing 4,150 horsepower, cruising speed 175 miles per hour, range 1,000 miles with a pay load of 9,200 pounds including 33 passengers.

Then passing to the future, the new designs, referred to above, proposed for trans-Atlantic flight, with a total life of 200,000 pounds, will have a wing area approximately of 4,450 square feet, a wing loading of 45 pounds, engines developing 11,750 horsepower, cruising speed 250 miles per hour, range 3,700 miles with a pay load of 25,000 pounds including 100 passengers.

In these figures for horsepower and speed, it should be noted that the power is the maximum developed by the engines, used normally only when taking off. The cruising power usually varies from 50 to 60 percent of this. With full power, the top speed would be some 25 to 30 percent higher than the cruising speed.

These illustrations are all of American design and manufacture. It must not be supposed, however, that we stand alone in this march of progress. England, France, Germany, Italy, and Russia are all thinking and designing along these same general lines. I shall attempt no comparisons since my purpose is simply to indicate the trend of progress, and for this purpose the American designs will serve as well as, or perhaps better than, those from abroad. I may, however, go so far as to say that no foreign design actually built appears to have the promise of the Boeing boat No. 314, and no designs, especially for trans-Atlantic service, appear to be in the class with those submitted in competition for the contemplated 200,000-pound type, to which I have just referred.

In summarizing the characteristics of these modern airplanes, the wing loading was noted as one of the significant features. This, we remember, is the total lift or total weight divided by the wing area—that is, the lift per square foot of area. Perhaps no character-

istic of an airplane shows more clearly the advance during the quarter century than does this figure. Twenty or 25 years ago each square foot of wing area was expected to lift some 8 to 10, perhaps 12 pounds. But with improved form and increased speed, these figures have been raised to 30 and 40 and above in recent designs. It may be of interest to note that for flying birds, this ratio is of the order of 2 to 4. This is due, in part at least, to the lower speed at which the bird flies, especially as compared with the modern trend in airplane speeds.

This brings us to the question of speed. A quarter of a century ago, airplane speeds were of the order of 50 to 80 miles per hour, and airplanes were chiefly for military or naval use. Today, cruising speeds of 150 to 200 miles per hour are the accepted normal, with top speeds considerably higher. What then is the outlook for the future? Is there a limit to the speed of the airplane? Here again, no one can safely predict. Suppose, however, we put the question a little differently, in this way. Assuming available the present content of the domain of science, engineering, and technology, with everything sacrificed to the one feature of speed, and supposing all of the factors affecting speed combined in the optimum manner and degree; what speed might we then expect? With the question put in this manner, it is possible to give at least an approximate answer and it works out to be somewhere about 500 miles per hour. How closely has this figure been approached? What is the present speed record? Here the answer is 424 miles per hour [2] held by an Italian seaplane. It should be noted, however, that such a plane has no commercial value. Everything has been sacrificed to speed. Almost the entire useful load has been given over to engine weight, leaving only a small margin for a few gallons of fuel and the pilot. The course is 2 kilometers or about a mile and a quarter. And thus, by a tour de force, as we may term it, with everything made subservient to this special purpose, this speed of 424 miles per hour has been attained, and speeds closely approaching 500 miles per hour appear to be quite within the framework of possible modern achievement, if we are willing to pay the price.

At the same time we should perhaps remember that outside the possibilities of commercial stratosphere flight, which are as yet unproven, it does not appear probable, in any near future and with the present content of science, engineering, and technology, that we shall much exceed 300 miles per hour for commercial planes and perhaps 400 miles per hour for the fastest military or naval fighting planes. In planes for actual service, the margin between total lift and the weight of the structure cannot be almost entirely given over to power

[2] Considerably higher speeds have been attained since the date of writing this paper.

plant. Some sensible part of the total lift must be allotted to fuel and to pay or fighting load and this means reduced power-plant capacity as compared with the plane where a short burst of speed is the sole object.

Let us now turn to another item of airplane performance—range, by which is meant the distance flown without grounding or refueling. Here again the answer depends on the special conditions imposed; and in particular on the division of the useful load between fuel and pay load. If we go to the limit, with no pay load whatever, with all of the margin between the total lift and the weight of the plane devoted to fuel, consumable supplies, and minimum crew, it again becomes possible to give an approximate answer to the maximum distance which can be flown. This distance works out to be from 8,000 to 9,000 miles; and this again, we must note, is a performance worked out within the framework of our present-day science, engineering, and technology. It does imply, however, everything made subservient to long-range flight—the maximum possible load of fuel, no head winds or adverse weather conditions, every element contributing to the desired result combined in the optimum manner and degree, and everything operating with the highest attainable efficiency throughout the entire flight. It also implies flying constantly with a speed such that there will always obtain a certain fixed optimum ratio between two characteristic coefficients of airplane performance—the so-called lift and drag coefficients. The first of these relates the lift of the plane to the speed, to the wing area, and to the density of the air in which the plane is moving. The second relates the drag, or resistance to motion, to the same conditions of the flight. Now it works out that for maximum range, or otherwise for maximum distance per pound of fuel, the ratio of these two coefficients—lift divided by drag—should be a maximum; and this implies a speed continuously changing with fuel consumption and with the consequent lightening of the plane—high speed at first when the plane is heavy and decreasing as the plane becomes lighter with the consumption of fuel, but always so adjusted as to meet this condition between these two coefficients.

When we ask how near has present achievement approached such a range as 8,000 or 9,000 miles, we find a somewhat wider gap. The present record is about 7,000 miles. When we realize, however, the remote chance, for a period of 60 to 80 hours, of a complete absence of all adverse weather conditions and a continuous perfect functioning, during this period, of all factors contributing to the desired end, the larger margin between actual and ideal performance is not surprising. It should also be noted that it is too much to expect practically a continuous exact regulation of the speed of the plane in

relation to its weight in such way as to give the required relation between the two coefficients of lift and drag referred to above.

Again, it is obvious that a performance such as this is without commercial or economic value. The plane with only its operating personnel is all that reaches the ultimate point. For economic purposes, there must be something in the way of pay load, and this necessarily reduces the possible supply of fuel and hence, correspondingly, the distance which can be flown. Reference to this point has already been made in speaking of carrying capacity. Here again, it is clear that with a large fraction of the useful load allotted to fuel, the plane will be able to carry a small pay load a relatively long distance, whereas with ony a small part allotted to fuel, a large pay load can be carried a relatively short distance. The question of pay load and range are therefore mutually dependent, the one varying inversely to the other within the limits of the total useful load available.

When we pass, then, to the question of commercial possibilities, we find, for example, that the present China Clippers, making the flight across the Pacific in successive steps of which the longest is something over 2,000 miles, can, for this distance and with a reasonable margin of fuel for adverse weather conditions, carry only a pay load so small that, admirable as they have been as engineering structures, they can scarcely be considered as economically suited to this service. For successive steps of the order of 1,000 miles, on the other hand, they would presumably be found economically well suited.

It is confidently expected by both designers and operators that the new Boeing flying boats already referred to, with a total lift of 82,500 pounds and carrying some 10,000 pounds of pay load over a range of 2,400 miles at a speed of 150 miles per hour, will prove distinctly superior in economic performance to the smaller boats which they are expected to replace for this service.

When we come to the question of trans-Atlantic service with an uninterrupted flight of about 3,000 miles, it will be safe to say that there are at present available no commercial craft capable of undertaking such service with a pay load sufficient to give good promise of economic success. For step-wise flight by way of Bermuda and the Azores or for the shortest possible flight from Newfoundland to Ireland, there are some possibilities. With reduced pay load or with no pay load, the trans-Atlantic crossing is becoming almost a commonplace.

Earlier reference has been made to the competitive designs that have been called for covering a structure that should give good promise of successful economic performance. It will be remembered that the specifications call for a structure weighing about 200,000

pounds and carrying a pay load of 25,000 pounds (including 100 passengers) at a cruising speed of 200 to 250 miles per hour and with a normal range of 3,700 miles but with fuel for a range in still air of 5,000 miles.

While we are thinking of the economic aspect of these matters, a few figures of cost may be of interest.

Thus if we take some of the most recent examples ranging in total lift from 42,000 pounds to the giant trans-Atlantic plane of 200,000 pounds, we find investment costs range between $7.15 and $8.65 per pound of gross lift, making the cost of the Boeing 307 of 42,000 pounds lift, $300,000, that of the new D. C. 4 of 65,000 pounds lift (now undergoing trials), $470,000, that of the present China Clippers of 52,000 pounds lift, $450,000, that of the new Boeing boat, No. 314, of 82,520 pounds lift, $612,000, and an estimated cost of the proposed trans-Atlantic craft of 200,000 pounds lift, $1,500,000.

For operation, the cost per hour for these planes, without stopping for the individual figures, ranges from $108 to $337 with a cost per mile from $1.62 to $1.23, and per passenger seat per mile from 1¼ cents to nearly 3 cents.

It is fair to say that the economics of these largest structures is by no means yet fully assured. Thus estimate places the cost per seat mile for the new Douglas 4 of 65,000 pounds total lift at 2.10 cents, which is practically the same as the figure 2.05 cents given for its predecessor the Douglas 3, with a total lift of only 24,000 pounds.

The same thought has apparently governed the design of a new Curtiss-Wright 30-passenger twin-engined plane which is approaching its first tests at St. Louis.

The total lift is 36,000 pounds with a cruising speed of 200 miles per hour at an altitude of 10,000 feet.

It appears to be a not unreasonable assumption that a structure of this relatively moderate size and capacity, but designed in the light of modern scientific advances, may prove economically well adapted to many types of air transport service.

Perhaps brief note may be made of a characteristic of airplane performance closely allied to range. That is, duration—the maximum time a plane can remain in the air regardless of distance flown. It will be seen that this characteristic is of no great economic significance. Obviously the economic purpose of an airplane is transport. It will be clear also that this requirement calls for the minimum consumption of fuel per unit of time rather than per unit of distance as in the case of range. Here again, if we assume everything subordinated to this one feature, and with similar assumption as before regarding the optimum combination of all factors affecting this one characteristic of performance, and likewise with no untoward

weather conditions to influence the result—with all these conditions assumed, it again becomes possible to determine with a fair degree of approximation the maximum duration of flight, regardless of distance flown. The answer works out to be from 90 to 100 hours. The present record is in the neighborhood of 85 hours.

In connection with range, note was made of a condition to be fulfilled affecting the relation between the two coefficients of lift and drag, and it will be recalled that for maximum range the speed must always be such as to put the plane in an attitude of flight such that the ratio of these two coefficients has its maximum value. For maximum duration there is a similar condition, but not the same. For the latter the fraction which must have its maximum value has for its numerator the coefficient of lift multiplied by its own square root and for the denominator the coefficient of drag as before. It may also be noted that the speed of the plane will be less for maximum duration than for maximum range.

The gap between present record performance and the figures given above is again readily explained by the difficulty of insuring almost perfect functioning of all the factors entering into the final result during a period of say 60 to 100 hours, including the absence of untoward weather conditions, and further by the fact that, owing to its small economic importance, there has been but little real attempt to extend this particular performance to its ultimate limit. Range is a much more important item of performance for all economic and commercial purposes, and has, therefore, attracted the major effort in this direction.

Let us now turn to another item of airplane performance—altitude. How high can a plane rise above the level of the sea? The extreme achievement here can hardly be said to have any economic or commercial significance. So-called stratosphere or substratosphere flights, to which I shall recur in a moment, are in the immediate foreground of present-day practice; but the extreme of possible and even present achievement in this direction lies far beyond the possibilities of immediate utilization commercially.

As in the preceding case of extreme performance, we assume everything about the plane and its loading made subservient to high altitude climb; and that these conditions are all combined in the optimum manner and degree and that throughout the climb all of these factors function together with the highest attainable efficiency. One more condition must be noted. The engine must be supercharged—that is, the air supplied to the engine for the combustion of the fuel must not be the thin rarefied air of the higher altitudes, but air at sea-level pressure or as near to that condition as may be found attainable. The logic of the situation is clear. Power is developed through the combustion of fuel, that is, its chemical union with oxygen. A fixed

volume of air is drawn into a cylinder of an airplane engine for every cycle of engine operation. Of this air about 23 percent is oxygen. At sea-level pressure and density, this will provide for the burning of a proportionate amount of fuel with the corresponding development of power. The same volume of air drawn in at the density of 20,000 feet elevation would have only 45 percent of the weight of oxygen at sea level with a corresponding reduction in power developed. The corresponding figures for altitudes of 30, 40, and 50 thousand feet would be respectively, 13, 18, and 11 percent of the oxygen at sea level.

It is, therefore, evident that if anything approaching full engine power is to be maintained at high altitudes, the air going to the engine must be precompressed to something approaching sea-level pressure and density. Or, put otherwise, the more nearly these conditions can be approached, the greater the power developed at altitude and the higher the altitude ultimately reached.

So then, combining this condition with those previously noted, it works out that an altitude approaching 60,000 feet is within the framework of possible achievement without trespassing on what might be considered the fantastic. The present record is close to 53,000 feet (52,937) held by an English pilot.

There are many difficulties and limitations against which the struggle for high altitude must be made. Only a few of the more serious can be here noted.

1. Of the total power developed by the fuel burned, only a part can be used for climbing, since a part must be made available for the precompression of the air, a part which grows ever larger and larger the higher the altitude achieved.

2. No matter where it is in climbing flight, the weight of the plane together with the vertical component of the drag must be balanced by the reaction of the air on the plane together with the vertical component of the pull of the propeller. But the weight of the plane remains constant, except for the decrease by way of the combustion of fuel, while the density of the air, on which lift depends, grows less and less with increasing altitude, thus calling for higher and higher speeds through the air. The resistance to motion, for the same speed, is indeed correspondingly reduced, so that higher speed becomes possible; but the actual relations are complex, and it works out that there is difficulty at the propeller (even with the modern variable-pitch forms) in transforming with high efficiency such power as it receives from the engine into useful propulsive work; and this difficulty increases the higher the altitude. Add to these difficulties reliable oxygen equipment for the pilot with clothing for protection against temperatures somewhere about 67° below zero, Fahrenheit, and it is seen that the attempt to scale the ultimate

in airplane altitude carries a challenge that can only be met by a combination of adequate engineering design with supreme judgment, skill, and daring on the part of the pilot.

This question of altitude flying brings us naturally to that of commercial flying at altitudes much less than those just noted, but still at an altitude that will permit of drawing a real advantage from the decreasing resistance to motion with decreasing density of the air and thus, within the conditions of commercial requirements, of realizing higher speeds of transport than would be possible with the same engine power at sea level. Already altitudes of 12,000 to 15,000 feet are the rule on long-distance flights.

We remember that the word "stratosphere" is used for an indefinite stratum of the atmosphere lying above an altitude varying somewhere about 35,000 feet, and above which the temperature of the air is nearly constant at about 67° below zero, Fahrenheit. Substratosphere flights may then be considered as those made in that stratum of the atmosphere lying perhaps between altitudes of 20,000 and 30,000 feet; though undoubtedly first approaches will be made at altitudes of 15,000 to 20,000 feet.

Within these limits the difficulties which are met with at altitudes of 40,000 to 50,000 feet and above are present in lesser degree, and it does appear possible to realize, commercially and economically, higher speeds of transport than at lower levels. The interaction of the various factors is very complex, and I shall make no attempt to discuss them in detail, but the general results of flights at altitudes of the order of 20,000 feet are already in the way of being put to commercial test.

For passenger transport, however, certain special conditions must be met. Most people can tolerate without difficulty altitudes of 10,000 to 12,000 feet. It is, of course, quite out of the question to provide passengers individually with oxygen masks and equipment. The only practicable solution for both passengers and operating personnel is to place the entire personnel, passengers and crew, within an airtight compartment of the plane in which, above say 10,000 feet, the air is kept, by the operation of a suitable compressor, always at a pressure and density corresponding to this altitude. This means a closed metallic structure capable of withstanding the excess pressure within the cabin against the reduced external pressure of higher altitudes. Thus with the cabin at the pressure for 10,000 feet and with the plane at 20,000 feet, this excess would be about 500 pounds per square foot. With the plane at 30,000 feet, the corresponding figure would be about 800 pounds per square foot.

Then again the engine must have its own quota of air; but here no compression up to the conditions for 10,000 feet will be acceptable. Full sea-level conditions, or as nearly so as may be practicable,

will be required. All of this means, of course, extra weight of plane and mechanical equipment, and here is where the limitation will enter with reference to extending such operation to extreme altitudes. But this is only the beginning of difficulties. The excessive cold of these higher altitudes means again artificial heat for the personnel, trouble with gasoline and lubricants, with possible serious trouble in de-icing windows and pilot's lookouts.

However, all these are merely hurdles to be passed over and in the very near future we may expect to see such flights on a commercial basis, at least in the lower altitude ranges.

The first plane, presumably, to achieve this distinction will be the Boeing No. 307, which has been designed definitely with reference to this character of service. As already noted, this plane has an ordinary cruising speed of 175 to 180 miles per hour. With 9,200 pounds of pay load, including 33 passengers, it will have a range of about 1,000 miles. The cost of this plane is given as $300,000 and it is understood that a certain number of these so-called "stratoliners" will very soon be put into actual service.

I have listed comfort as one of the requirements of air transport, but I shall not tarry long over this feature. It will be enough to say that the developments during the past 10 years have held constantly in view increased comfort and convenience for the passenger. Soundproofing, reclining chairs by day or bunks for sleeping accommodations by night, meals as usual, the attentions of courteous and capable stewardess-hostesses—these, especially in modern large transport planes, have gone far to give to the air passenger a close approach to Pullman accommodations by rail, though naturally with less freedom of personal movement. Comfort and convenience, though counted on to attract and hold passenger patronage, are, after all, of minimum interest technically. It will always be a simple matter to provide these features, up to the limit of weight and space available, in competition with other and perhaps more important requirements.

We have thus passed rapidly in review some of the problems in modern air transport with indications of the direction of recent advance. We must now turn to what is, after all, the most important consideration of all, and that is safety.

If we ask what is the most common menace to safety, the natural answer will be the weather. But the weather is simply one of the conditions under which the plane must render its service. Our guiding principle, in the matter of the relation between weather and safety, should, I think, be this: We must strive to secure a degree of safety in what we may call "proper flying weather" which will at least approach that in the safer modes of land travel; and we must strive to perfect our methods of observation and analysis of weather

conditions and of the transmission and reception of such intelligence to such degree as shall serve for a reasonably adequate determination of the quality of the weather over any proposed route with reference to this standard; and if, over the proposed route, the weather falls outside this characterization, the flight should be canceled.

Now from the viewpoint of the plane and its services, in what way may accidents arise? Without attempting too much detail, we may say that accidents find their causes chiefly in—

1. Faulty aerodynamic characteristics.
2. Failure of the structure.
3. Failure of motive power.
4. Failure of, or inadequate, navigational equipment.
5. Inadequate or erroneous information received from the services on the ground.
6. Human errors.

Again with regard to weather conditions, those which present major hazards are:

1. Rain, snow, and fog, especially the two latter in degree requiring blind flying.
2. Violent winds, air vortices, extreme turbulence.
3. Temperatures below freezing under atmospheric conditions which may involve the loading of the plane with ice or frozen snow.
4. The electrical state of the air—not primarily with reference to the hazard of a lightning stroke, but chiefly by reason of the interference with the services of radio communication.

A brief word with reference to these sources of potential hazard.

With our present knowledge of the aerodynamic characteristics required for safety and with the intensive study which is being given to refinements in these matters, we may, I think, feel confident that present design is, and future design will be, free of fault in its aerodynamic characteristics in any degree likely, with proper handling, to involve a major hazard in service.

With regard to the structure of the airplane, I think we may also say that the problems involved in the design and construction of the major parts of an airplane structure are now so well in hand that, in commercial service especially, major structural failures should become almost unknown. In this particular we may claim close approach to an entirely reassuring condition—a condition indicated by the rarity, in recent years, of accidents resulting from major failures of the structure of the plane itself.

Failure of the motive power, including engine and propeller, may have its source either in the structural elements themselves (for example a broken crankshaft or propeller blade), the exhaustion of the fuel supply, or in stoppage due to disturbance in the somewhat delicate conditions involved in carburetion and ignition, or, again, in failure in the adequate lubrication of all rubbing surfaces.

Structurally, the element of hazard here should be brought close to a point comparable with that in the main airplane structure. In the matter of operation, as long as we employ a type of fuel involving carburetion and electric ignition, it now seems difficult to see how all hazard of interruption is to be avoided. However, an answer here is found in multiple power units. At the present time the accepted standard in large air transport structures is four independent power units, any two of which should insure adequate power for the safe handling of the plane, at least to the nearest landing field. It seems hardly within the limits of probability that two power units would fall into trouble at the same time, and thus, with four such units, of which three or in any event two, would always be available, we should have assurance of adequate power for safety under any conditions which can be foreseen.

Hazards resulting from carburetion, ignition, and the danger of fire following a crash, could be minimized by the use of the Diesel-type engine with fuels of the so-called safety type. At present, however, this would involve some sacrifice either of performance or of pay load and seemingly in our present temper we are slow to forego the service which present conditions give us, in exchange for this added margin of safety.

With regard to navigational equipment, there is no excuse for any lack of the best of such equipment now available, and certainly on all major lines of transport, there *is* no such lack. It is obvious that at all times the pilot must have the means of knowing his speed, his altitude, the direction in which he is flying and whether in a straight or curved path. He must also know where he is, as nearly as possible, and hence the distances and directions of nearby landing fields. He must also be able to ask for and receive information by radio on any and all matters affecting his flight.

Normal instrumental equipment with adequate services from the ground will give him all this, except as weather conditions (fog, snow, electrical disturbances, etc.) may interfere.

There is room here, however, for improvement, for which we may look with confidence in a near future. One of the most important of these problems is that of bringing a pilot from altitude, under blind flying conditions, to a safe landing on the field beneath him. It is relatively easy to guide a pilot to a point in the air over an airport. It is less easy to guide him down, blind, to a safe landing.

Very definite progress has been made toward the solution of this problem, and quite recently a most noteworthy advance has been reported—a new form of radio beam for blind landings—bringing the plane safely to the landing field in fog or thick weather. I must not take the time for detail, but this promises to be an outstanding advance over all previous methods for blind landings, and to give

good assurance of safe landings under all conditions of visibility. At the present time the chief navigational hazards result from conditions requiring blind flying, and from electrical conditions of the atmosphere interfering with radio transmission and reception.

Steady improvement is being made in equipment designed to meet these and other conditions affecting safety, and only this past fall four distinct advances in equipment making for safety were announced. These are:

1. The radio echo altimeter for indicating the absolute distance from the ground, instead of the altitude above sea level, as with the standard type of instrument now used.
2. A new form of static suppressor which it is hoped will go far toward eliminating this serious hazard to radio communication between the plane and sources of needed information.
3. A new form of automatic direction finder for guiding the pilot to a source of radio wave with which he is in tune. This device may also be connected up with the automatic gyropilot in such way as to provide automatic blind flying toward the source of the radio waves.
4. A device for indicating approach to the dangerous condition known as the "stall"—meaning an approach to an angle of attack so great that the plane will pass out of control of the pilot and probably fall into a spin.

These are all steps forward along the general line of greater safety in air transport.

Turning for a moment to services on the ground, we find here, perhaps, at the present time, the largest opportunity for improvement. In recent years, funds far too small have been made available for improvement in the various agencies which are intended to supply the pilot at all times with reliable information on all matters affecting the safety of his flight. This condition must be corrected and improved; and with an adequate utilization of all that is now known and available in the science and art of meteorology, radio, and airport equipment, the causes of many casualties in the past would be removed.

There remain, to be reckoned with, human errors. We can hardly hope that we can ever entirely eliminate this potential hazard to safety. Rigid requirements for license as a transport pilot with retests from time to time have given us a highly trained and highly reliable body of pilots for this service; but there is, and, so far as I can see, there will always remain some residual hazard of human error—a hazard, however, which may be minimized in some degree by the presence always of a copilot ready to assume control in any case where corrective control might save the day.

Not to delay too long over this matter of safety, I can summarize my own feelings in the matter by saying that I cannot see, in any future within the scope of present vision, a reduction of the margin

of air-transport hazard to a point comparable with the safest of land-transport means. There are too many additional avenues of potential hazard. On the other hand, there is hazard in all agencies of transport, a hazard in automobile transport for example; but we do not on that account hesitate to freely employ the automobile. In comparison with the service which it stands ready to afford, we accept this means of transport, with such marginal hazard as there may be. In the same way, it is obvious that the air-traveling public now accepts such measure of hazard as may inhere in this mode of transport, in view of the service which the airplane is prepared to offer. And in this respect, I believe that we may look for continuing improvement in all of these matters affecting the safety and security of air transport; and that with the continued application of the resources of science and art to these problems, the residual margin of hazard in this form of transport will be reduced to a point where it will be accepted rather generally and without hesitation in view of the service which it is prepared to render—possibly with almost the same readiness with which we now use the automobile in the affairs of our everyday life.

In this connection some figures published in the last report of the National Safety Council will be of interest. They are admittedly based on incomplete and somewhat uncertain data, but may perhaps be accepted as showing the general trend. The figures in column A are passenger fatalities per 100,000,000 miles of travel; those in column B, total fatalities, including operating personnel.

	A	B
Railroad trains	0. 09	9. 9
Automobiles and buses	4. 5	7. 8
Scheduled air-transport planes	10. 1	13. 5
Nonscheduled planes	162. 2	165. 2

Thus, according to these figures, the hazard in scheduled air transport planes is about twice that in automobiles and buses and about 100 times greater than in railroad trains. It may also be noted that these figures are based on total estimated mileages as follows:

Railroad trains	22, 460, 000, 000
Automobiles and buses	408, 000, 000, 000
Scheduled air-transport planes	435, 740, 000
Nonscheduled planes	99, 900, 000

The time which I should occupy in this address is near its term. Perhaps, however, I should say a word regarding lighter-than-air-craft, the airship. The tragic end of the *Hindenburg* is still fresh in our minds as well as our own story of disaster in the *Shenandoah*,

the *Akron*, and more recently the *Macon*. Two questions present themselves. Can the airship be built with a reasonable margin of safety? And, granting this, what is its promise for economic and effective commercial service?

First we must specify that the airship shall be inflated with helium gas. Our world monopoly of the supply of this gas is, of course, a matter of common knowledge. The use of this chemically inert gas will completely dispose of the hazard which caused the loss of the *Hindenburg*, inflated, as she was, with hydrogen gas. With this hazard eliminated, we have left the normal hazards of failure of the structure under adverse weather conditions. The record of the *Graf Zeppelin* in her around-the-world trip and later in regular commercial service between Germany and South America, together with the record of the *Hindenburg* aside from the fatal hydrogen conflagration, go far to prove, in commercial service, a high degree of safety and security. Thus, for the *Graf Zeppelin*, we have a record of about 17,000 hours of flying service over about 1,000,000 miles of distance with safe carriage of 13,000 passengers on 144 ocean crossings. Similarly for the *Hindenburg* up to the time of her destruction, the record shows 3,000 hours in flight, 210,000 miles distance, with the safe carriage of 3,059 passengers. Mention may also be made of the record of the small airships comprising our own Goodyear "blimp" fleet, with the appearance of which, at least, I presume we are all familiar. This shows, to the end of 1937, 112,379 flights covering 67,847 hours in the air and 3,010,000 miles of distance, with a total of 302,248 passengers carried with no casualties or even injuries.

If you ask me to explain our own less favorable record with a loss of three naval ships out of four which we have operated, I could perhaps make the attempt, but it is too long a story. The designs of the *Akron* and *Macon*, the most recent ships designed and built in this country, date back now 10 years. During that period we have learned much with regard to the hazards for which airships must be prepared. Especially is this the case with regard to the stresses on the control surfaces in gusty, turbulent air. We know now that the structure of these surfaces with their supporting framework was not adequate to meet the stresses to which they might be subjected under such adverse weather conditions as must occasionally be expected, especially when serving as an adjunct to a naval fleet, rather than on commercial service.

Not only has experience taught dearly bought lessons regarding these matters, but certain programs of research carried on in the Airship Institute at Akron, Ohio, have thrown much additional light on this subject. Still other recent programs of research at

the Goodyear Zeppelin Corporation in Akron have helped to bridge the gap between the loads which the elements of the structure must sustain and the dimensions of these elements in order that such loads may be carried with a suitable margin of safety.

The story is too long and the subject is too complex for any discussion in detail. I believe, however, that a fair conclusion is that with the full utilization of recent advances in both the science and art of airship design and construction, we can now design and build airships with a margin of structural safety and security at least equal to that for the airplane. So far as further comparison goes, the airship is relieved of two possible hazards affecting the airplane—propulsive failure followed by a forced landing, and control failure followed by the too often fatal spin.

On the whole, there seems to be no reason why our future airships—in case any such be built—should not show an excellent record as regards safety and security in operation.

With regard to the field for successful commercial service, present opinion in the United States is divided. I shall not take the time to discuss the pros and cons but will only venture my own opinion that for transocean service on relatively long nonstop runs (3,000 to 6,000 miles) with relatively heavy loads at speeds three times those of surface ships though perhaps only one-half to one-third those of the airplane, but with greater passenger freedom and comfort than for the airplane, there may well be found a useful and effective place for the airship in our complex system of modern transport.

Something might also be said regarding the possible use of the airship in naval warfare; but here again the question is highly controversial and I shall not venture into this domain.

Perhaps, also, if you will bear with me, I should say a word about the autogyro and the helicopter. The former is sustained by rotating wings or vanes, maintained in rotation by the motion of the structure under the pull of an air propeller, driven by an engine much as in the conventional airplane.

The latter is, in effect, simply a flying propeller. The shaft, nearly vertical, is tilted so that the upward component of the total pull provides sustenation, while the horizontal component provides transport.

The autogiro, now some 10 years old, seems to be in the way of acquiring a fairly well-assured place among the varied forms of aircraft available for air transport. It appears to have special qualities which go far to adapt it to individual use: take-off from, and landing in, confined areas, and relative safety against casualty from loss of control as may occur with conventional airplane forms.

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Present speeds are moderate—125 miles per hour perhaps—and it is not easy to see, in this type of construction, a serious rival to the conventional form for either high speed or heavy weight carrying, as in the modern conventional forms referred to earlier. As a relatively safe "family carriage," however, this type does appear to have possibilities, and its future development will bear close watch.

The true helicopter appears finally to have made its appearance in Germany, though detailed information is lacking. With the shaft vertical in still air, this type of structure is capable of vertical ascent or descent. In moderate wind with the shaft inclined against the wind, the same results are possible. When a suitable altitude has been reached, the shaft is inclined so as to give a forward component to the pull of the propeller, and a horizontal component to the motion results. This type of structure has long been the subject of repeated effort. It is too soon to prophesy as to what place it may be able to take in the field of air transport. As with the autogiro, it does not seem likely that speeds comparable with those attainable with conventional forms can be hoped for. With the development, however, and satisfactory solution of the problem of control in the air—a problem somewhat troublesome with both the autogiro and the helicopter—it may well take its place with the autogiro in types of service where the special characteristics of these forms meet peculiar and limiting conditions.

Air transport is the newest of those agencies whereby we move things about (ourselves included) over the face of the earth. Transport is one of the major factors which has given us the profound differentiation between the physical conditions of our modern life as compared with the life of our forebears of the centuries gone by. Until 1903 our movements were, so to say, two-dimensional. With the achievement of the Wright Brothers, in 1903, a third dimension was opened up. Man began to fly. And so air transport is only an infant among other and older agencies, one regarding which many problems yet remain for study and solution; but, withal, an infant of lusty growth and seemingly destined to go far. The mission of air transport is to serve the public; and to render such service acceptable, continuously improving combinations must be found of the distinguishing characteristics: safety, economy, weight-carrying capacity, speed, and comfort. The story of the past 36 years gives good ground for faith in the future and that the unfolding years will indeed bring such improving combinations in full measure with basic advances in science and technology—advances on which all improvement in the material content of our lives must depend.

THE STORY OF THE TIME CAPSULE[1]

By G. Edward Pendray

Assistant to the President, Westinghouse Electric & Manufacturing Co.; Chairman, Westinghouse Time Capsule Committee

[With 4 plates]

Ever since archeologists and historians turned their talents to deciphering the unrecorded past, human beings have dreamed of simplifying the problem for scientists of the future, deliberately preparing a message from our time to theirs.

Until recently this perennial dream has been only a dream. The problem of preserving such a record is extremely difficult. Crypts on the earth's surface, no matter how strong, offer obvious temptation to vandals. Most materials suitable to be deposited in the earth are subject to rapid corrosion, or are too brittle or too difficult to find after burial. Too little was known about the effects of time to permit anyone confidently to design a vessel for the future.

A few months ago engineers of the Westinghouse Electric & Manufacturing Co. decided that the advance of technology had removed these difficulties at last, and what hitherto had seemed impossible could now be done.

Early in 1938 they decided upon building a "Time Capsule" capable of lasting 5,000 years—a period of time almost as long as that of all recorded history. Five thousand years ago the pyramids were still unbuilt. The peoples of that time had discovered metals, and were using metallic alloys. They had learned how to write down human speech, and record language on clay tablets and stone. They understood commerce; they knew how to build huge cities. But they had not yet devised the alphabet, and they did not know of the existence of iron.

Five thousand years from now the peoples of the future will look back upon us as we look back on the early Egyptians, Sumerians and Babylonians. It was the plan of Westinghouse engineers to provide them with more knowledge of us than we have of any of the ancient peoples who lived before us.

[1] Reprinted by permission of Westinghouse Electric & Manufacturing Co.

THREE MAJOR PROBLEMS

This project clearly required the solution of three great problems.

The first was, how to build a vessel capable of lasting 5,000 years, and how to preserve it for posterity.

The second, how to leave word of its whereabouts for historians of the future.

The third, the selection and preservation of its contents.

Each of these problems was carefully considered. At each step, counsel was taken with archeologists, historians, technical and scientific men, hundreds of whom participated with Westinghouse in the working out of this project. A Time Capsule Committee was formed, which established subcommittees to study the various questions relating to the plan.

A subcommittee headed by M. W. Smith, Westinghouse manager of engineering, undertook the solution of the first problem: that of designing and constructing the Time Capsule. It was decided that the best material would be a metallic alloy of high corrosion resistance and considerable hardness, nonferrous (containing no iron), and preferably consisting principally of copper, oldest of the metals used by man.

A new alloy of copper, known as Cupaloy (copper 99.4 percent, chromium 0.5 percent, silver 0.1 percent) was found most nearly to fulfill the specifications. Like that reputed to have been used by the ancient Egyptians, the secret of which has been lost, this metal can be tempered to the hardness of steel, yet has a resistance to corrosion equal to pure copper. Also—of great importance—in electrolytic reactions with iron-bearing metals in the soil it becomes the anode and therefore will receive deposits instead of wasting away, as do buried water pipes and other iron alloys. Moreover, Cupaloy is especially resistant to corrosion in salt water.

For reasons of strength and convenience, the Time Capsule was shaped like a torpedo, 7½ feet long and 8⅜ inches in diameter. The outer shell consists of seven cast segments of Cupaloy, threaded, screwed together hard, and sealed with molten asphalt. The nearly invisible joints have been peened out and the outer surface burnished. The walls of the Cupaloy segments are 1 inch thick, thus leaving an inner crypt 6⅜ inches in diameter and 6 feet 9 inches long. The crypt is lined with an envelope of Pyrex glass, set in a water-repellent petroleum base wax. Washed, evacuated and filled with humid nitrogen, an inert, preservative gas, this glass inner crypt contains the "cross section of our time."

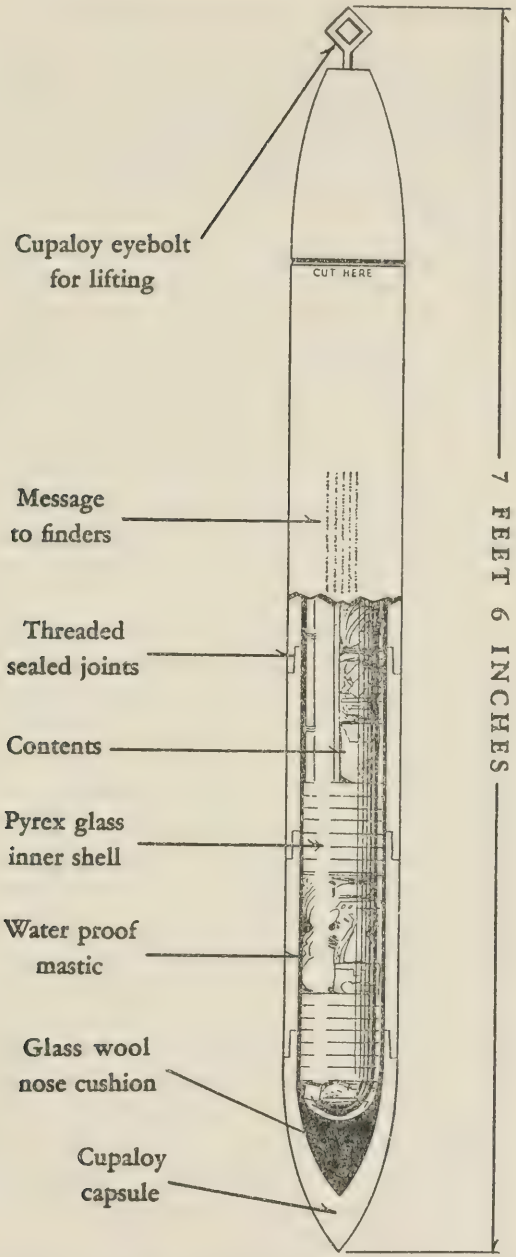


FIGURE 1.—Schematic cross section of the Time Capsule, showing construction.

FOR THE GUIDANCE OF "FUTURIANS"

The second great problem, that of how to leave word of the whereabouts of the Time Capsule, was met by preparing a Book of Record of the Time Capsule, printed on permanent paper with special inks. Copies have now been distributed to libraries, museums, monasteries, convents, lamaseries, temples, and other safe repositories throughout the world.

The Book of Record was prepared after detailed consultation with libraries, museum authorities, printers, and bookbinders. Suggestions for binding and general treatment were obtained from the office of the National Archives, the New York Public Library, the American Library Association and other sources. The United States Bureau of Standards furnished specifications for the permanent paper and inks. A special run of 100-pound rag book paper was manufactured for the book. The pages of each copy were sewn together by hand with linen thread. A portion of the edition was bound in royal blue buckram stamped with genuine gold. The remainder was bound in handmade flexible paper, stamped with aluminum.

In order that the appearance of the Book of Record might match its permanence, Frederic W. Goudy, one of the foremost type designers, typographers, and printers of our time, consented to design the book and set a portion of the type. Exactly 3,650 copies were printed, of which 2,000 (including one buried in the Time Capsule) were bound in flexible paper, and 1,650 in buckram.

The Book of Record contains a message to posterity asking that it be preserved and translated into new languages as they appear; a description of the Capsule's contents, and the exact latitude and longitude of the deposit as determined by the United States Coast and Geodetic Survey to the third decimal point in seconds. The geodetic coordinates are tied into the Survey's national network, on which astronomical as well as geodetic data are given. In addition, instructions are included for making and using instruments to locate the Time Capsule by the methods of electromagnetic prospecting.

That our tongue may be preserved, the book contains an ingenious Key to the English Language devised by Dr. John P. Harrington, of the Smithsonian Institution. By means of simple diagrams the peculiarities of English grammar are explained; a mouth map shows how each of the 33 sounds of English are pronounced. A 1,000-word vocabulary of High Frequency English spelled in the ordinary way and neophonetically, is provided. In itself the key is believed to contain all the elements archeologists of the future will need to translate and pronounce 1938 English, but, to make doubly certain, the Time

Capsule itself also contains multilingual texts, a dictionary and a lexicon of slang and colloquial English.

Also contained in the Book of Record are messages to the future from three famous men of our time: Dr. Albert Einstein, Dr. Robert Millikan, and Dr. Thomas Mann. A table of common measures in the English and metric systems is given, including a statement of the length of the standard meter in terms of the wave length of red cadmium light—a constant that will never vary, no matter what other systems of measurement are in use 5,000 years from now.

SELECTING THE CONTENTS

Choosing what was to go into the limited space of the Time Capsule crypt proved perhaps the most difficult problem of all, because nothing short of an enormous gallery of vaults could accommodate all the objects and records of any civilization.

The Time Capsule Committee turned for advice to archeologists, historians, and authorities in virtually every field of science, medicine, and the arts. On the basis of their helpful suggestions, the Committee chose to include some 35 articles of common use, ranging from a slide rule to a woman's hat, each selected for what it might reveal about us to the future archeologists. Also included are about 75 samples of common materials, ranging from fabrics of various kinds, metals, alloys, plastics, and synthetics, to a lump of anthracite and a dozen kinds of common seeds.

These material items, however, are only supplementary to a voluminous essay about us and our times, reduced to microfilm. On three and a half small reels there are reproduced books, articles, magazines, newspapers, reports, circulars, catalogs, pictures; discussing in logical order where we live and work, our arts and entertainment, how information is disseminated among us, our general information, our religions and philosophies, our education and educational systems, our sciences and techniques, our earth, its features and peoples; medicine, public health, dentistry and pharmacy, our major industries, and other subjects. This "Microfile" comprises more than 22,000 pages of text and 1,000 pictures; a total of more than 10,000,000 words. It would take an ordinary person more than a year to read all of it; more than a decade to assimilate all this knowledge. Probably no man living knows as much about us as those who study this Time Capsule will know.

A small microscope is included for reading the microfilm; also instructions for making a larger, more comfortable reading machine, such as those used in libraries and newspaper offices for this purpose. There are likewise instructions for making various kinds of modern instruments, including a motion picture projection machine. For

use with this, three reels of newsreel are contained in the Time Capsule, showing about 20 characteristic, significant, or historic scenes of our times, complete with sound, and ranging all the way from an address by President Roosevelt to a Miami fashion show. The newsreel was especially edited for the Capsule by RKO-Pathe Pictures, Inc.

PACKING THE TIME CAPSULE

The utmost care was taken in packing the contents. Under the direction of representatives of the United States Bureau of Standards each object was examined to determine whether it could be expected to last 5,000 years. All articles containing volatile solvents were ruled out; also all materials which might decompose with the production of fumes or acids that might attack other articles in the crypt. No liquids of any kind were permitted in the crypt. Organic objects, such as seeds, were sealed in special gas-tight glass capsules.

Every object enclosed in the Capsule was then fully labeled and described. The glass capsules containing seeds and other objects contain labels sealed into the glass. All other objects were individually wrapped in heavy 100-percent rag ledger paper and tied with linen twine, with the label wrapped inside. Where it was necessary to use paste to attach a label, only pure gum arabic was used. Film, including both the microfilm and newsreel, was enclosed in special spun aluminum containers, lined with rag paper.

The position of each object in the crypt was determined by its weight. The heavier objects are packed in the bottom, resting on a cushion of glass wool. The seven containers of film rest about midway in the crypt. The lighter objects, including the woman's hat, are placed on top. The hat was stuffed with surgical cotton to preserve its shape, and wrapped in paper. All spaces between the objects in the crypt were cushioned and made firm with glass wool.

The process of packing was conducted in the presence of three official witnesses: C. G. Weber, of the United States Bureau of Standards; F. D. McHugh, managing editor of the Scientific American, and Grover Whalen, president of the New York World's Fair 1939. A checklist of contents, bearing the signatures of the witnesses, was the last thing included in the crypt.

Immediately following the packing, the Pyrex inner crypt was placed upon a glass-lathe, heated and sealed. The air was then drawn out through a small tube, the contents washed with inert gas, and the crypt filled with nitrogen, to which just enough moisture was added to equal the humidity of an ordinary room. Protected from oxygen and excess moisture by this inert, humid atmosphere, the contents are expected to remain in their present condition

indefinitely. When archeologists of the future open the Time Capsule they will probably find the film, fabrics, metals and other materials as fresh and "new" as the day they were put in.

The final step in the preparation of the Capsule was the insertion of the glass inner crypt into the outer Cupaloy shell. Before this was done, the Pyrex envelope was wrapped with several layers of glass tape to increase its strength. Both the Cupaloy outer shell and the packed crypt were then gently warmed in electric ovens to encourage the flow and penetration of the waterproof wax. After the inner crypt was in place, the Capsule was raised upright, and the wax poured in around the glass. "Shrink-fitting" the final Cupaloy joint was then accomplished by chilling the heavy cap to several degrees below zero with dry ice, then turning it into place on tapered threads. When permitted to warm up to the same temperature as the rest of the Capsule, the natural expansion of the metal caused the threads to seize so tightly as to form an air-and-water-tight joint.

DEPOSITING THE CAPSULE FOR THE FUTURE

The Time Capsule is preserved for posterity at the site of the New York World's Fair 1939; chosen because New York will certainly be an attractive place for archeologists 5,000 years from now, as are the sites of ancient Athens, Rome, and Troy in our own time.

It was lowered 50 feet into the earth on the site of the Westinghouse Building at the grounds of the World's Fair at high noon on September 23, 1938, the precise moment of the autumnal equinox. While a Chinese gong tolled solemnly, A. W. Robertson, chairman of the board of the Westinghouse Electric & Manufacturing Co., committed the Time Capsule to posterity with these words: "May the Time Capsule sleep well. When it is awakened 5,000 years from now, may its contents be found a suitable gift to our far-off descendants."

The Capsule made its descent into the earth through a steel pipe 10 inches in diameter, and came to rest upon a block of waterproof cement. Before this well is finally closed, the Capsule will be entombed in pitch and an additional layer of concrete, after which the steel pipe will be cut off and withdrawn. The land where it lies will become a city park after the fair, and the site of the Time Capsule may be marked with a shaft or boulder. During the fair a replica of the Capsule, and duplicates of all the objects, books, and other items it contains, will be on view at the Westinghouse Building.

SAFE FROM VANDALISM AND SINKING

Many questions are asked about the Time Capsule project, the principal one being, how will it be protected from thieves or persons whose curiosity is greater than their sense of obligation to the future?

The problem of keeping the Capsule safe from vandals is believed to be well taken care of by the site selected for burial. Sunk 50 feet below the surface of the ground, in swampy soil, recovery will involve an expensive and difficult engineering operation, costing many times the possible intrinsic worth of the Capsule for its metal and salable contents.

Another question often discussed is whether, 5,000 years from now, the coast will have sunk so far as to drown the area. Consultation with geologists and the United States Coast and Geodetic Survey indicate that there is probably no foundation for the common notion that the east coast is sinking. Surveys extending over the last 40 years show that if there is any sinking at all, the rate is so slow that the change in level in 5,000 years would be only a few feet. The elevation at the site of the Time Capsule is about 20 feet above sea level.

As to the third question frequently asked: Will it ever be found again? Westinghouse engineers can only reply that every precaution has been taken through the Book of Record to guide archeologists of the future to the exact spot. If the people of the distant future wish to find it they can probably do so, even though it should migrate in the earth, or sink. And even if all else fails, we may depend on the perennial curiosity and the digging and burrowing habits of the human race to unearth it sooner or later. In the words of Dr. Clark Wissler, dean of the scientific staff of the American Museum of Natural History, and one of the foremost archeologists in the United States:

> We have been told that such efforts as ours here are futile; that, after all existing civilizations have died out and new civilizations come to be, no one will find this record, or if they do perchance discover it, they will not be able to make anything out of it. But the chances are good that these records will be found and that they can be interpreted.

COMPLETE LIST OF CONTENTS

The contents of the Westinghouse Time Capsule fall into five groupings:

1. *Small articles of common use* that we wear or use, or which contribute to our comfort, convenience, safety, or health. About 35 in number, these articles are separately described and pictured in the microfilm essay. In addition, labels and descriptions are wrapped with each.

2. *Textiles and materials.* About 75 in number, these comprise swatches of various types and weaves of cloth, samples of alloys, plastics, cement, asbestos, coal, etc. Each is described in the microfilm essay, and a further description of the composition, nature, and use is wrapped with each sample.

3. *Miscellaneous items.* Seeds, books, money, type, special texts, etc.

4. *An essay in microfilm*, comprising books, speeches, excerpts from books and encyclopedias, pictures, critiques, reports, circulars, timetables, and other printed or written matter; the whole producing in logical order a description of our time, our arts, sciences, techniques, sources of information, and industries. The essay, divided into 15 subsections, contains the equivalent of more than 100 ordinary books; a total of more than 22,000 pages, more than 10,000,000 words and 1,000 pictures. A microscope is included to enable historians of the future to read the microfilm; also included are instructions for making larger reading machines such as those used with microfilm in modern libraries.

5. *Newsreel.* Characteristic or significant scenes in sound film prepared by RKO-Pathe Pictures, Inc., for the Time Capsule. Instructions for making a suitable projection machine to use this film are included in the microfilm Microfile.

Details appear on the following pages, in the order above described.

NOTE.—Where several competitive items of equal archeological value were available, but only one could be included, the item selected was chosen by lot. The name of the maker, when given in the following list, is provided only for type and style identification. Choice of any article for the Time Capsule is not to be interpreted either as a special endorsement of that article or a reflection on the quality of any competing article.

1. ARTICLES OF COMMON USE

CONTRIBUTING TO CONVENIENCE, COMFORT, HEALTH, SAFETY:

Alarm clock.
Can opener.
Eyeglasses, bifocals (Bausch & Lomb).
Fountain pen (Waterman).
Mazda electric lamp (Westinghouse, 60-watt, 110-volt).
Mechanical pencil (Waterman).
Miniature camera (Eastman, Bantam K. A., special f.4.5. lens).
Nail file.
Padlock and keys (The Yale & Towne Manufacturing Co.).
Safety pin.
Silverware—knife, fork, spoon (Heirloom plate, Grenoble pattern, by Wm. A. Rogers Ltd., Oneida Ltd. Successor).
Slide rule (Keuffel & Esser). (Also instructions for use.)
Tape measure (Keuffel & Esser).
Tooth brush.
Tooth powder in small container.
Transmitter and receiver of ordinary handset telephone.
Watch (small wrist watch for woman).
Westinghouse Sterilamp (bactericidal).

FOR THE PLEASURE, USE, AND EDUCATION OF CHILDREN:

Boy's toy—a mechanical, spring-propelled automobile.
Girl's toy—a small doll.
Mickey Mouse child's cup of plastic material (Bryant Electric Co.).
Set of alphabet blocks.

PERTAINING TO THE GROOMING AND VANITY OF WOMEN:

Woman's hat, style of autumn 1938 (designed specially by Lilly Daché).
Cosmetic make-up kit (Elizabeth Arden Daytime-Cyclamen Color Harmony Box, including two miniature boxes of face powder, lipstick, rouge, eye shadow).
Rhinestone clip (purchased at Woolworth's).

PERTAINING PRINCIPALLY TO THE GROOMING, VANITY, OR PERSONAL HABITS OF MEN:

Container of tobacco.
Electric razor and cord (Remington-Rand Close Shaver with Westinghouse motor, General Shaver Corporation).
Package of cigarettes.
Safety razor and blades (Gillette Aristocrat one-piece razor, Gillette Safety Razor Co.).
Smoking pipe (Drinkless Kaywoodie, Kaywoodie Co.).
Tobacco pouch, closed with zipper (Alfred Dunhill, of London).

PERTAINING TO GAMES PICTURED AND DESCRIBED IN MICROFILE:

Baseball.
Deck of cards.
Golf ball (Kro-flite, A. G. Spalding & Bros.).
Golf tee.
Poker chips.

2. MATERIALS OF OUR DAY

FABRICS:

Asbestos cloth (Johns-Manville).
Cotton swatches (Jas. McCutcheon & Co.).
Glass fabric samples (Westinghouse glass tape).
Linen swatches (Jas. McCutcheon & Co.).
Rayon swatches (Du Pont and Celanese).
Rubber fabrics (Lastex cloth, United States Rubber Products, Inc.).
Silk swatches (Jas. McCutcheon & Co.).
Wool swatches (American Woolen Co.).

METALS AND METALLIC ALLOYS:

Hipernik (Westinghouse).
Aluminum (commercially pure sample from Aluminum Co. of America).
Aluminum high-strength alloy (ST 37 alloy furnished by Aluminum Co. of America).
Carbon steel (Electro Metallurgical Co.).
Chromium (Electro Metallurgical Co.).
Copper (Westinghouse Research Laboratories).
Ferromanganese (Electro Metallurgical Co.).
Ferrosilicon (Electro Metallurgical Co.).
Ferrovanadium (Electro Metallurgical Co.).
Iron (pure sample from Westinghouse Research Laboratories).
Magnesium high-strength alloy (Dowmetal, furnished by Dow Chemical Co.).

METALS AND METALLIC ALLOYS—Continued.

Manganese (Electro Metallurgical Co.).
Silicon (Electro Metallurgical Co.).
Stainless steel (Electro Metallurgical Co.).
Temperable copper (Cupaloy, furnished by Westinghouse).
Hipersil (Westinghouse).
Tungsten wire (filament for Westinghouse Mazda Electric lamp).

NON-METALLIC MATERIALS AND SUBSTANCES:

Airplane pulley of laminated phenol plastic Micarta—Westinghouse.
Anthracite coal (sealed in glass, furnished by Anthracite Institute).
Artificial cellulose sponge (E. I. du Pont de Nemours & Co., Inc.).
Artficial leather.
Asbestos shingle (furnished by Johns-Manville).
Beetleware—a specimen of urea plastic (Westinghouse).
Carborundum (The Carborundum Co.).
Glass wool.
Linen packing thread.
Leather samples—tanned cowhide, genuine morocco (goatskin).
Lucite—a specimen of methyl methacrylate plastic (du Pont).
Manufactured rubber (tire section furnished by Fisk Tire Co., Inc.).
Micarta—a specimen of phenol plastic (Westinghouse).
Noiseless gear of laminated phenol plastic Micarta—Westinghouse.
Paper—four kinds of permanent rag paper used in money, books, permanent ledgers, and for special wrapping.
Portland Cement (sample furnished by Portland Cement Co., sealed in glass).
Raw rubber (furnished by United States Rubber Products, Inc.).
Transite—a specimen of material made of asbestos and cement (Johns-Manville).
Rock wool (Johns-Manville).
Synthetic "rubber" (Neoprene Chloroprene, furnished by du Pont).

3. MISCELLANEOUS ITEMS

MONEY OF THE UNITES STATES:

Dollar bill, silver dollar, half dollar, quarter dollar, dime, nickel, penny.

ELECTRICAL ITEMS:

Electric wall switch (Bryant Electric Co.).
Electric lamp socket (Bryant Electric Co.).

SEEDS (SELECTED AND FURNISHED BY U. S. DEPARTMENT OF AGRICULTURE. ALL SAMPLES SEALED IN GLASS TUBES):

Wheat, corn, oats, tobacco, cotton, flax, rice, soybeans, alfalfa, sugar beets, carrots, barley.

BOOKS (ALL OTHER BOOKS, REPORTS, ETC., REDUCED TO MICROFILM):

Selected leather-bound rag-paper copy of the Holy Bible.
Copy of the Book of Record of the Time Capsule.

TYPE (SUPPLEMENTARY TO DISCUSSIONS IN MICROFILE):

Handset type—capital and lowercase alphabets of Goudy Village No. 2 type, 14 point.
Linotype—8 point Caslon 13 em slug set on standard Linotype in the shop of the Tuckahoe Record, Tuckahoe, N. Y. The line reads: "This type set by Linotype Machine."

Optical Instrument (other optical instruments described in microfile):
Magnifier and viewer for use with microfilm and newsreel film.

Special Texts (written on permanent paper in nonfading ink):
Special messages from noted men of our time (Albert Einstein, Robert A. Millikan, Karl T. Compton, Thomas Mann).
Certificate of official witnesses at packing of the Westinghouse Time Capsule.
Message from Dr. Thornwell Jacobs, president of Oglethorpe University.
List of Westinghouse men whose suggestions, guidance, engineering, and other special skills made the Time Capsule possible.

4. SCENARIO OF MICROFILM SEQUENCES

INTRODUCTION

1. Greetings.
2. Directions for making a larger projection machine.

AIDS TO TRANSLATION

3. Explanation of keys.
4. Fable of the North Wind and the Sun, in 20 languages.
5. The Lord's Prayer in 300 languages.
6. The Practical Standard Dictionary. Funk & Wagnalls, New York, 1938.
7. Dictionary of Slang and Colloquial English, by John S. Farmer and W. E. Henley. 6th Impression. E. P. Dutton & Co., New York.

WHERE WE LIVE AND WORK

8. Introduction.
9. Individual homes. Architectural Forum, pages from various 1937–38 issues.
10. Apartments, by Harvey Wiley Corbett. Encyclopaedia Britannica,[2] vol. 20, pp. 870–881.
11. The Trailer. Catalogue of Kozy Coach, Kalamazoo, Mich., 1938.
12. Offices, by Harvey Wiley Corbett. Encyclopaedia Britannica, vol. 2, pp. 274–287.
13. The story of Rockefeller Center, 1938.
14. Office Equipment, by W. H. Leffingwell. Encyclopaedia Britannica, vol. 16, pp. 712–719.
15. Office machines. Catalogue of International Business Machines Corporation, 1938.
16. Factories. Encyclopaedia Britannica, vol. 9, pp. 29–31.
17. Photograph of Westinghouse East Pittsburgh Works.
18. Photograph of Westinghouse Transformer Works, Sharon, Pa.
19. Photograph of Westinghouse Elevator Works, Jersey City, N. J.
20. Photograph of headquarters of General Motors Corporation, Detroit, Mich.
21. Photograph of first stages on assembly belt in General Motors factory.
22. Photograph of press that makes automobile tops out of cold steel.
23. Photograph of rolling cold steel, American Iron & Steel Institute.
24. Photograph of pouring molten iron into a furnace, American Iron & Steel Institute.

OUR ARTS AND ENTERTAINMENT

25. Introduction.
26. The Arts, by Hendrik Willem van Loon. Simon & Schuster, New York.

[2] Wherever references is made to the Encyclopaedia Britannica, we have used the 14th Edition, 1937.

27. Painting. Encyclopaedia Britannica, vol. 17, pp. 36–65.
28. Arozco Frescoes.
29. "Guernica"—Pablo Picasso.
30. "American Landscape"—Charles Sheeler.
31. "Summer Wind"—Alexander Brook.
32. "Promenade"—Charles Burchfield (1928).
33. "Lower Manhattan"—John Marin (1920).
34. "Persistence of Memory"—Salvador Dali (Catalan).
35. "Daughters of the Revolution"—Grant Wood (American 1932).
36. "Composition Black, White & Red"—Piet Mondrian (Dutch).
37. "Dr. Meyer-Hermann"—Otto Dix.
38. Sculpture. Encyclopaedia Britannica, vol. 20, pp. 198–231.
39. Music. Encyclopaedia Britannica, vol. 16, pp. 3–24 (with score).
40. Harmony. Encyclopaedia Britannica, vol. 11, pp. 203–212.
41. Finlandia, by Jean Sibelius.
42. The Stars and Stripes Forever, by John Philip Sousa.
43. The Flat-Foot Floogee, by Slim Gaillard, Slam Stewart and Bud Green.
44. Photograph of Arturo Toscanini, one of our great directors, conducting a symphony orchestra.
45. Photograph of a string quartet.
46. Photograph of vocal soloist accompanied by orchestra, with audience in foreground.
47. Photograph of diners dancing to the accompaniment of an orchestra in a famous New York night club.
48. Catalog of instruments, showing construction, range, and how to manipulate.
49. Literature: introduction.
50. The essay. Encyclopaedia Britannica, vol. 8, pp. 716–717.
51. Freud, Goethe, Wagner, by Thomas Mann. Alfred A. Knopf, New York, 1937.
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53. Verse. Encyclopaedia Britannica, vol. 23, pp. 96–98.
54. The novel. Encyclopaedia Britannica, vol. 16, pp. 572–577.
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57. The Theater, by George Jean Nathan. Encyclopaedia Britannica, vol. 22, pp. 21–41.
58. Best Plays (1936–37), by Burns Mantle. Dodd, Mead, New York.
59. Motion Pictures, by Terry Ramsaye. Encyclopaedia Britannica, vol. 15, pp. 854–871.
60. Music Hall program for "You Can't Take It With You," September 1, 1938.
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62. The Story of Radio, by Orrin E. Dunlap, Jr. Dial Press, New York, 1935.
63. A radio studio, National Broadcasting Co., New York City.
64. Radio Corporation of America Building, Rockefeller Center, New York.
65. Master switchboard of the National Broadcasting Co.
66. Director of radio dramatic program, National Broadcasting Co.
67. Radio broadcasting antenna.
68. Radio actors "on the air."
69. Standard Bridge Rules. R. H. Macy & Co., New York, 1938.
70. Photo of a bridge tournament. Acme.
71. Hoyle's Card Rules. R. H. Macy & Co., New York, 36th Edition, 1938.
72. Typical poker scene. Acme.
73. Spalding's Rules of Golf—1938.
74. Typical golf match. Acme.

75. Spalding's Football Rules—1938.
76. Scene from football game.
77. Spalding's Baseball Rules—1938.
78. Scene from baseball game.

HOW INFORMATION IS DISSEMINATED AMONG US

79. General introduction.
80. Magazines: introduction.
81. Saturday Evening Post, May 7, 1938.
82. Collier's, September 3, 1938.
83. Ladies' Home Journal, September 1938.
84. Woman's Home Companion, September 1938.
85. Vogue, September 1, 1938.
86. McCall's, September 1938.
87. Good Housekeeping, September 1938.
88. Adventure, September 1938.
89. Love Story, September 3, 1938.
90. True Confessions, October 1938.
91. Complete Western Book Magazine, September 1938.
92. Detective Story Magazine, October 1938.
93. Amazing Stories, October 1938.
94. Weird Tales, September 1938.
95. American Mercury, September 1938.
96. Time, February 28, 1938.
97. Newsweek, July 25, 1938.
98. Reader's Digest, September 1938.
99. Harper's Magazine, August 1938.
100. The Atlantic Monthly, July 1938.
101. Scientific American, September 1938.
102. Life, May 23, 1938.
103. Look, September 13, 1938.
104. Your Life, September 1938.
105. Fortune, February 1938.
106. New Yorker, September 3, 1938.
107. Introduction: A Magazine of the prehalftone era.
108. Leslie's Weekly, several issues.
109. Newspapers: introduction.
110. New York Herald Tribune, August 24, 1938.
111. New York Times, August 19, 1938.
112. New York World-Telegram, August 10, 1938.
113. New York Sun, January 8, 1938 (complete final).
114. New York Post, September 6, 1938, sports extra.
115. New York Journal American, July 14, 1938.
116. New York Daily News, August 30, 1938.
117. New York Mirror, August 29, 1938.
118. Daily Worker, August 30, 1938.
119. The cartoon: introduction.
120. Batchelor's "In the Spring a Young Man's Fancy * * *" Chicago Tribune-New York News Syndicate, 1938.
121. Talburt's "Land of the Rising or Setting Sun?" New York World-Telegram Syndicate, 1938.

122. Kirby's "Laughter for the Gods," New York World-Telegram Syndicate, 1938.
123. The "Funny Paper": introduction.
124. Caniff's "Terry & the Pirates," Link's "Tiny Tim," and "Dill and Daffy," Chicago Tribune-New York News Syndicate, June 25, 1938.
125. Willard's "Moon Mullins" and Branning's "Winnie Winkle the Breadwinner," Chicago Tribune-New York News Syndicate, June 25, 1938.
126. Gray's "Little Orphan Annie," and Gould's "Dick Tracy," Chicago Tribune-New York News Syndicate, June 25, 1938.
127. King's "Gasoline Alley," and Edson's "The Gumps," Chicago Tribune-New York News Syndicate, June 25, 1938.
128. Segar's "Sappo," and "Thimble Theater," King Features, Sunday, September 18, 1938.
129. Knerr's "Dinglehoofer & His Dog," and "The Katzenjammer Kids," King Features, September 18, 1938.
130. Disney's "Mother Pluto" and "Mickey Mouse," King Features, September 18, 1938.
131. DeBeck's "Bunky" and "Barney Google," King Features, September 18, 1938.
132. Cady's "Peter Rabbit," New York Herald Tribune Syndicate, September 4, 1938.
133. Webster's "Timid Soul," New York Herald Tribune Syndicate, August 7, 1938.
134. Webster's "The Thrill that Comes Once in a Lifetime," New York Herald Tribune Syndicate, August 27, 1938.
135. Our books: introduction.
136. Methods of Printing, by G. Leonard Gold.
137. Design and Beauty in Printing, by Frederic W. Goudy. Press of the Woolly Whale, March 8, 1934.
138. A History of the Printed Book, by Lawrence C. Wroth. Limited Editions Club, New York, 1938.
139. Color in Use. International Printing Ink Corporation, copyrighted 1935.
140. Color as Light. International Printing Ink Corporation, copyrighted 1935.
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BOOK OF GENERAL INFORMATION ABOUT US

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160. Introduction.
161. The World Atlas. Rand McNally, New York.
162. Our races: introduction.
163. The world's races. Encyclopaedia Britannica, vol. 2, pp. 41–50.
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170. Frontiers of Medicine, by Dr. Morris Fishbein. Williams & Wilkins, Baltimore, June 1933.
171. Men of Medicine. The March of Time, Issue No. 11, vol. IV.
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173. Report of the Surgeon General of the United States, June 30, 1937.
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OUR INDUSTRIES

178. Introduction.
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198. Photograph of welding the new office building at the Westinghouse Transformer Works, Sharon, Pa.
199. "Putting in the Throw" on a 7,500 kv.-a. synchronous condenser at the Westinghouse East Pittsburgh Works.
200. Photograph of tightening a "steel spider" at the Westinghouse East Pittsburgh Works.
201. Photograph of assembling giant mill motors at the Westinghouse East Pittsburgh Works.
202. Photograph of Ignitron tubes in the Westinghouse Research Laboratories.
203. Photograph of testing a grid-glow tube in the Westinghouse Research Laboratories.
204. Photograph of a lamp machine in the Westinghouse Lamp Works, Bloomfield, N. J.
205. Photograph of bottom one-third of 800-foot vertical antenna of Westinghouse radio station KDKA, Pittsburgh, Pa.
206. Photograph of a 1938 hostess inspecting complete meal cooking in Westinghouse Automeal Roaster at Merchandise Works, Mansfield, Ohio.
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233. Pan American timetable, July 1, 1938.
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276. Northern Pacific timetable, corrected to June 20, 1938, Form 5111.
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282. Weaving. Encyclopaedia Britannica, vol. 23, pp. 455–466.
283. Dyeing. Encyclopaedia Britannica, vol. 7, pp. 789–795.
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286. Women's Wear Style Sheet, 1938.
287. Women's Wear for September 1, 1938.
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NEW YORK WORLD'S FAIR 1939

289. Introduction.
290. Message from Grover Whalen, President of the World's Fair.
291. New York, the World's Fair City.
292. World's Fair Bulletin, A Year from Today.
293. World's Fair Bulletin, Participation Issue.
294. World's Fair Bulletin for June 1938.
295. List of officers and department heads of the World's Fair.

THE OBJECTS IN THE CAPSULE

296. Introduction and list.

THE MEN WHO MADE THE CAPSULE

297. List.

HOW WE APPEAR, TALK, AND ACT, AND SCENES OF OUR DAY

298. Introduction.
299. Technology of amateur and professional motion pictures. Encyclopaedia Britannica, vol. 15, pp. 867–871.
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303. How to build a projection machine (diagrams and photos).
304. A projection machine.

NEWSREEL

Characteristic or significant scenes in sound film, prepared for the Time Capsule by RKO-Pathe Pictures. Instructions for making a suitable projection machine for the use of this film are included in microfilm Microfile.

The newsreel runs about 15 minutes. It comprises the following scenes:

1. Franklin D. Roosevelt, President of the United States, speaking at Gettysburg, Pa., July 3, 1938, on occasion of the seventy-fifth anniversary of the celebrated battle of the United States Civil War. Veterans of both sides, attending their final reunion, are present.
2. Howard Hughes, celebrated aviator, who made around-the-world flight as "Air Ambassador" for New York World's Fair 1939, in 3 days, 19¼ hours, July 1938.
 a. Plane flying over New York City's skyscrapers as Hughes sets out on first lap.
 b. Hughes' return at Floyd Bennett Field, New York City, after completing flight.
 c. Hughes' New York reception, showing enthusiastic crowds lining the streets and paper showering down from skyscrapers.
3. Jesse Owens, American Negro athlete, winning 100-meter dash in 1936 Olympic games.
4. Collegiate football: Harvard-Yale, November 1936 at Yale Bowl, New Haven, Conn. Yale wins 14–13.
5. Baseball: Big League—All Star Game at Crosley Field in Cincinnati, Ohio, 28,000 spectators—July 1938. Nationals defeat Americans 4–1.
6. United States Pacific Fleet setting out for 6 weeks of maneuvers, showing battleships in formation off Long Beach, Calif., in March 1938.
7. Soviets celebrate International Labor Day, May 1938, in Red Square, Moscow, Russia. Two shots of soldiers marching.
8. Greatest demonstration of military prowess in the United States since the World War, at Fort Benning, Ga., April 1938, showing tanks and other war machines.
9. Bombing of Canton, typical episode in the undeclared war between China and Japan. Canton, China, June 1938.
 a. Pathe cameraman, A. T. Hull, wearing helmet, in cockpit of plane, about to take off to make pictures.
 b. Smoke rising from explosions off in distance.
 c. Terror-stricken civilians in street.
 d. Red Cross men and women, many of whom are injured while ministering to the victims.

10. Fashion Show at Miami, Fla., April 1938.
 a. General view of luxurious scene in which the audience is seated around a swimming pool, watching models displaying advance summer fashions.
 b. Two girls in long beach coats.
 c. Two girls in long beach coats opened to reveal bathing suits, wearing enormous straw hats.
 d. Afternoon dress.
 e. Flowered print afternoon dress, with large hat.
 f. Another afternoon dress with brilliantly colored accessories, and large hat.
11. Preview of World's Fair 1939, May 1938.
 a. Motorcade of nearly 500 vehicles and floats, including the prize-winning Westinghouse float, going up a street in downtown Manhattan between sidewalks lined with crowds, under shower of paper.
 b. Sports float with Babe Ruth, baseball hero.
 c. Motorcade entering partially completed fair grounds.
 d. Fiorello LaGuardia, Mayor of New York City, and Grover A. Whalen, President of the Fair, in reviewing stand at fair grounds.
 e. Theme float, bearing replica of Trylon and Perisphere.



AN 800-POUND "PARCEL" TO BE DELIVERED IN THE YEAR 6939.



1. CASTING THE CAPSULE'S SHELL IN MOLTEN CUPALOY.

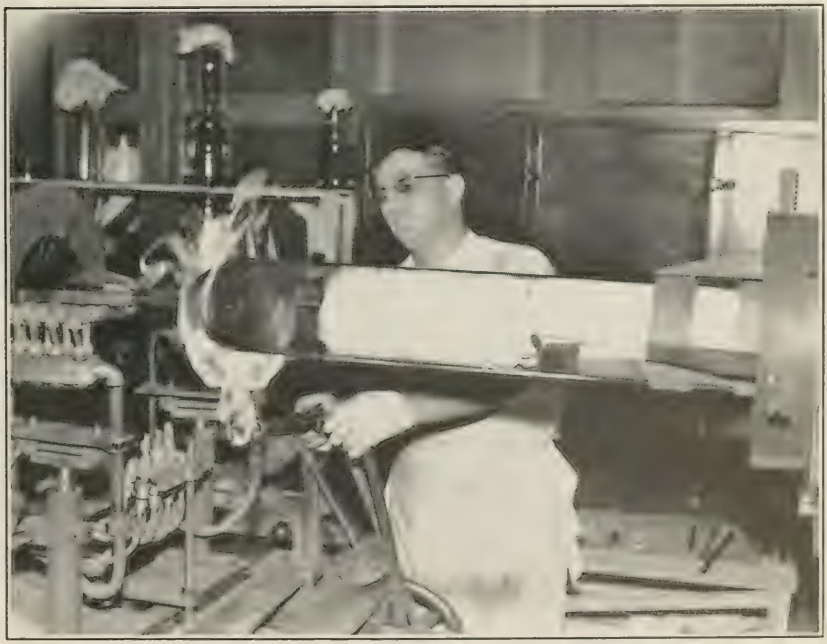


2. WESTINGHOUSE TIME CAPSULE BEGINS TO TAKE FINAL FORM IN THE EAST PITTSBURGH WORKS OF THE WESTINGHOUSE ELECTRIC AND MANUFACTURING COMPANY.



1. WITNESSES AT THE TIME CAPSULE'S PACKING.

F. D. McHugh, executive editor of Scientific American Magazine; D. S. Youngholm, vice president of Westinghouse Electric and Manufacturing Company; C. G. Weber; and seated, Grover A. Whalen, president of New York World's Fair Corporation.



2. SEALING THE PACKED INNER CRYPT WAS A DELICATE TASK.



LEFT, A. W. ROBERTSON, WESTINGHOUSE CHAIRMAN, AND GROVER A. WHALEN, GUIDE THE TIME CAPSULE TO ITS LONG RESTING PLACE.

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